the journal of INDUSTRIAL ENGINEERING

PRESENTATION OF THE RESULTS OF AN INDUSTRIAL ENGINEERING STUDY
By Ralph J. Beuter 287

THE ERROR OF ESTIMATE IN SYSTEMATIC ACTIVITY SAMPLING
By H. O. Davidson, W. W. Hines and T. L. Newberry 290

SOLUTION METHODS FOR WAITING LINE PROBLEMS
By John R. Shelton 293

PACE—A NEW INDUSTRIAL ENGINEERING TECHNIQUE FOR MANAGEMENT
By D. N. Petersen 304

RELATIVE IMPORTANCE FACTORS IN LAYOUT ANALYSIS
By Irvin L. Reis and Glenn E. Andersen 312

NEW CONCEPTS OF THE LEARNING CURVE
By E. B. Cochran 317

OBJECTIVE ASPECTS OF COMPUTER FACILITY DESIGN
By Robert P. Larsen 328

CONTROL CHARTS FOR QUEUEING APPLICATIONS
By R. W. Llewellyn 332

THE EFFECT OF INFLATION ON REPLACEMENT
By H. G. Thuesen and P. E. Torgersen 336

MARINE CONTAINERIZATION, CAUTION!
By Gerald A. Fleischer 338

A TIME FORMULA SOLUTION FOR AIR FORCE REWAREHOUSING STANDARDS
By David W. Anderson and Robert K. Cave 342

TOWARD A UNIFIED CONCEPT OF JOB DESIGN
By Elwood S. Buffa 346

READER COMMENTS 351

PRESIDENT'S COMMENTS
By Alex W. Rathe 352

PROFESSIONAL RELATIONS 353

INSTITUTE INTERESTS 355

RECENT READABLES 360

I. E. OPPORTUNITIES 362

JULY-AUGUST 1960

VOLUME XI NUMBER 4

OFFICIAL PUBLICATION OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.

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Subscription Prices: $10.00, one year; $17.00, two years; single issue, $2.50.

All Manuscripts for review should be submitted with drawings suitable for reproduction to the Editor-in-Chief, Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia.

Advertising Rates available from Editorial Office. Send copy and cuts to Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia.

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Presentation of the Results of an Industrial Engineering Study

by **RALPH J. BEUTER**

Industrial Engineer, Boeing Airplane Company

MANY products launched on the market have failed to sell, not because of any shortcomings of the product, but because of the way in which they were presented. American merchants have developed the greatest market in history by presenting products in terms and forms that the public accepts. Customers don't buy products—they buy results in the form of prestige, comfort, safety, enjoyment, and satisfaction. Toothpaste is not sold in terms of precipitated chalk, detergent and flavoring. It is sold on the basis that it will keep your teeth looking nice; it will eliminate mouth odors; it will protect your teeth. Products must be presented in terms the customer understands and accepts. A product presented as a "garment that will retain the same modules and hysteretic characteristics even after six months of exposure to body oils, soaps, detergents and oxidizing atmospheric gases" would probably receive only limited acceptance, whereas the same product presented as "These girdles won't loose their shape, they keep you looking younger longer" has sold thousands of Playtex girdles.

So it is with an Industrial Engineering study. You may have lived with a problem for days, weeks or months. You may have collected all sorts of data. You may have developed a solution that will save $50,000 a year. But unless the man or men to whom you present your findings can except and understand them, your chances of making a sale are slight. This doesn't mean that you can make a slipshod study, dress it up with some fancy words, a few pretty charts and make a sale. You may make one or even two sales on this basis, but it is not the formula for lasting success. As the American public recognizes basic quality in the products it buys, so too, your management will recognize quality in the studies you submit for acceptance.

As an Industrial Engineer, your selling job is doubly difficult. A merchant with a product has something concrete to sell. The customer can visualize himself driving a new car or wearing a new suit. It is probable what you are proposing is intangible and in addition, you are really trying to sell the benefits that accrue from the adoption of your proposal. How can this be done?

THE SITUATION

Let's assume that you have just been given an assignment. Right there you have an advantage. Someone has recognized a problem and this is where the sale begins. Now is the time to start the foundation of your presentation by establishing confidence in the fact that you are the man to solve this problem. Your training, education, and past performance, all contribute toward the establishment of the necessary confidence. However, the way in which you conduct yourself can outweigh any other factors. Volumes have been written about the qualifications required to be an Industrial Engineer, but we have all met the man who will glibly refer to TMU's or fatigue factors when he is talking to people who think that algebra is for the "long hairs." This may give the engineer a reputation for intelligence, but it is more likely that he will be tagged as a "smart aleck."

Why establish confidence? Because confidence is the first step toward communication, and communication is the major step toward cooperation. Someone must implement the results of your proposal and you will probably be dealing with him while making the study. It is hard enough to go into an area where it is obvious that the results of your study will probably result in change. You don't want these people to feel that any changes you recommend are capricious or poorly founded. You do want to establish the feeling that you have their best interests as well as the company's best interest at heart. This is a big order, but it can be done if you approach your work with sincerity, integrity, and humility.

THE FINISHED STUDY

Let's assume that you have completed the study. You have gathered your data, analyzed them, developed various hypotheses, tested them and selected the best solution. Now what? You have the facts, know their implications, and know what should be done. Now, look at the result from the customer's point of view. What's in it for him! This is what will finally sell your proposal. Did you solve the assigned problem? If not, what will it take to convince the originator of the assignment that some other problem is basic, and it is this problem that must be solved. Finally, and most importantly, in what terms does this man think? If you must sell the company comptroller on the purchase of some new equipment, you might talk or write in financial terms. On the other hand an up through the ranks factory manager would probably be interested in production rates, direct labor costs,

set-up charges and quality. Think in the terms that your customer will understand *easily*. If you are dealing with an engineer, you might refer to the torque characteristics of a motor as it affects production, or you might tell a production man "this motor doesn't waste time getting up to speed."

METHODS OF PRESENTING THE RESULTS OF AN ENGINEERING STUDY

You can submit results and recommendations in the form of a written report, verbally to an individual, or verbally to a group of interested people. Verbal presentations can and should include visual aids such as flip charts that will help you make your point. Each method has its advantages and disadvantages. Each method has conditions under which it is the best. Probably the most important of these is the desire and method of operation of the man or men who are in a position to accept or reject your recommendations. If he, or they, prefer simple written reports, it would be foolish to develop a complex verbal presentation complete with slides and flip charts. However there is nothing to preclude the use of a combination of methods such as a written report followed by a group presentation.

THE WRITTEN REPORT

Volumes have been published on how to write reports and business letters. This paper makes no pretense of reviewing all that has been written on the subject. Suffice it to say, that you are selling the benefits available from the adoption of your recommendations, not the techniques employed. Include enough data to support your recommendations. State what it will take to obtain the benefits, and close with a request for affirmative action.

A written report can be read and studied at the manager's convenience, but it must compete with hundreds of other documents that flow over his desk. Keep your report simple! If it is difficult to read or appears complicated, it may be filed for future reference and then forgotten.

THE VERBAL PRESENTATION TO AN INDIVIDUAL

You are now a salesman with a product. Therefore, let's think in terms of selling.

The saleman's function is to bring good news to the customer. You have something he needs, something that is of benefit to him. The product is good. You made the study, you know the facts and are convinced that your proposal will do the job. If this isn't so, postpone the presentation until you can develop this degree of confidence and enthusiasm.

Try to set a time for the presentation when your customer will have time to listen to what you have to say. It may be a good idea to tell his secretary what you are trying to do and enlist her aid in selecting a convenient time.

A good salesman meeting a prospective customer generally starts off with a pleasant greeting and then may indulge in some small talk. Why does he do this? Isn't this just a waste of time which could be used to make more calls and more sales? No! He might cut out the small talk and make more calls, but he would probably make fewer sales. A skillful salesman will use the "small talk" period of his presentation to establish a communications link with his prospect. He recognizes that people, like icebergs show only what is above the surface, but nine-tenths of the bulk is hidden.

The conscious, or thinking portion of the mind may be compared to the face and hands of a watch, and the subconscious may be compared to the works. The conscious mind thinks, but it can't do much without the storehouse of thoughts and ideas supplied to it by the subconscious. It uses these ideas to evaluate what it sees and hears. The conscious mind can not function without the subconscious, although the subconscious can function without the conscious. The conscious mind is alert and stands guard—sometimes reacting with negative aggression when presented with a new idea. The subconscious tends to be flexible and willing to entertain what seems interesting without protest if no deep seated prejudices are violated. If you tell a man, "I have the only possible solution," the conscious mind will spring to the defensive and challenge the statement. If, on the other hand, you ask, "Would you like to reduce customer complaints about deliveries", the reaction prompted by the subconscious would be, "Yes! But how can I do this?". It is the subconscious with which the salesman is trying to establish contact.

If you can get the customer to agree, "Yes, that is what I would like to have", you are in a position to begin your presentation. State what you propose to do, how you propose to accomplish it, and why this will result in the benefit desired. This presentation must have integrity, which can only be achieved through an honest concern for the customer's point of view. If you can not demonstrate that the presentation is tailored to the customer's needs or desires, it will lack integrity and the customer's conscious mind will reject it. Any extravagant claims will rob the presentation of the dignity which is required to impart dignity to the manager's decision to accept your proposal. Every one clings to certain dignities. The dignity of birth and personal superiority are important to us all, but the most precious dignity is the right to make our own decisions. Imprisonment, society's greatest punishment (excluding execution), is the denial of the right to make one's own decisions. The manager to whom you are making a presentation must feel instinctively that his decision to accept your proposal is sound, voluntary and in accord with his own best interests. If this is not the case, his conscious mind will reject your proposal.

If you have kept your presentation logical and proved what you originally proposed, nothing less, nothing more,

you should be able to let the close come as a natural outcome of the presentation. This is the time to refer back to the original accord—"Mr. Jones, you agreed that. . . ." Then refer back to the proof—"The charts we reviewed show. . . ." Finally, suggest affirmative action, "Would you care to call in Mr. Black so that we can schedule the time for revising the layout?" or "Shall I prepare a letter summarizing our agreement on these points?" The important thing at this point is to avoid any indication of pressure. The manager must feel that the decision is his to make. After this is done, *leave*. You have accomplished your purpose and any further discussion at this point may bring out questions that can only serve to delay matters or weaken your position.

PRESENTATIONS TO A GROUP

Generally, the same rules apply to group presentations as apply to individual presentations. The meeting place should be arranged and ready before the meeting starts. Chairs should be available, ash trays empty and charts in place. This is common courtesy and prevents unnecessary delays that irritate busy managers. There is no sense in starting with a hostile audience.

In starting the meeting you again have the problem of establishing a communication link with your audience. When speaking to a group you can't address each individual. Therefore, your opening statements must be carefully phrased to avoid arousing the conscious objection of anyone in the room. If one person vocalizes "negative aggression" at this point, you have an up hill fight. Try to avoid statements that will put anyone on the defensive. A *good* salesman doesn't knock the competitor's product or use a scapegoat. He simply shows the superiority of his product. You should do the same!

Allow more time to make a presentation to a group than you would for making it to an individual. You can proceed no faster than the slowest person in the room can follow. Different people will be slower at different points. Watch your audience! Are they attentive? If not, you may have to speed up, slow down, talk louder, or start asking questions. If they aren't paying attention, they don't hear you; and if they don't hear you they can't agree with what you are saying. Then, at the end of the presentation, someone will probably have a question, which may be on a point already covered, or it may be completely irrelevant. This can lead to a discussion that can lead away from your main purpose—agreement to your proposal—and thereby scuttle your presentation and possibly your entire study. The presentation should close in much the same manner as that of an individual presentation—refer back to the original advantages proposed—briefly review the proof—request affirmative action.

SUMMARY

An Industrial Engineer, to be successful, must be able to obtain acceptance of the results of the studies he makes. He should therefore understand some of the principles of selling.

1. The engineer should *develop the customer's confidence* in his ability to make a good product (study).
2. *Sell the benefits* that accrue from adopting the proposals, not the techniques used or even the study itself.
3. Approach the presentation of the study results from the *customer's point of view*.
4. Use terms that the *customer can easily understand* and accept.
5. *Establish contact* with the customer's subconscious mind. Don't antagonize the customer's conscious mind with flat statements.
6. Permit the customer the *dignity of making his own decisions*.
7. *Organize the presentation* in a logical sequence.
   a. Obtain agreement that the benefits available from adopting your proposals are desirable.
   b. State what you propose to do.
   c. Prove that your proposal will deliver the desired results.
   d. Refer back to the agreement and briefly review proof.
   e. Request affirmative action.

REFERENCES

(1) Brewster, R. C., "More Psychology in Selling," *Harvard Business Review*, Vol. 31, No. 4, p. 91.
(2) Pollock, T., "How to Use the Powerful Question—What's in It for Me," *Management Methods*, August 1959.

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The Error of Estimate in Systematic Activity Sampling

by **H. O. DAVIDSON**

Vice President, Industrial Engineering, Operations Research Incorporated

W. W. HINES *and* **T. L. NEWBERRY**

Instructors, School of Industrial Engineering, Georgia Institute of Technology

AN APPLICATION of sampling theory by L. H. C. Tippett (5) to the taking of industrial time studies has led to the extensive employment of techniques known generally in this country as "Work Sampling" and in Great Britain as "Activity Sampling." In brief, these techniques employ a sample of instantaneous observations on the "activity state" of a man, machine, or process to estimate the percentage of time that is spent in various states. Thus, if a process may be in either of two states, A and A' (non-A), Tippett showed that by taking a sample of spot observations randomized in time, the problem could be treated as one of Bernoulli trials with success defined as (process in state A), with the probability of success at any observation being p_A the true proportion of time in which the process was in state A over the time period covered by the study. Accordingly, the sample proportion provides an unbiased estimator of the universe proportion, and a confidence interval may be calculated by application of the binomial variance formula.

DISADVANTAGES OF RANDOM SAMPLING

Techniques patterned after Tippett's application have proven extremely useful in manpower and equipment utilization studies, in the collection of data for analysis of queueing problems, and in other kinds of investigations. However, the randomizing of observation times has been both a nuisance and a source of inefficiency in the utilization of observers. To avoid these disadvantages some investigators have employed motion picture cameras arranged for time-lapse photography and actuated by random interval timing devices. While photographic records must still be interpreted by analysts, the method does permit efficient programming of the analysts' time which is not the case in the instance of randomized direct observation.

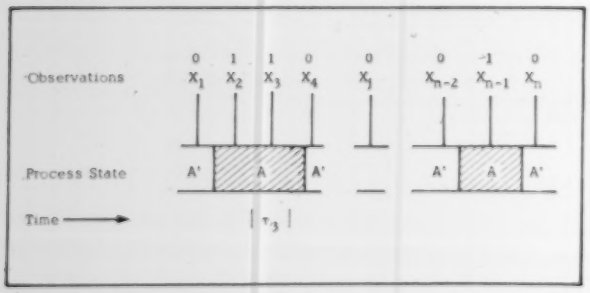

FIG. 1

In spite of the advantages that may pertain to use of the camera instead of the human as an instrument for randomly spaced observations, this approach to the problem seems rather like attempting to remodel a new horse to fit an old saddle. The camera is particularly suited to economical fixed interval observation, and it is difficult to believe that there is any real necessity of complicating the instrumentation with additional equipment to secure random intervals. Moreover, in studying processes one is frequently interested in discovering not only the relative frequency of certain states but also their time of occurrence and approximate duration (since they are not often truly "random"). A fixed interval observation scheme is superior for this purpose to a set of random observations. Finally, there are instances where with human observers a fixed interval sampling schedule would have definite practical advantages over randomized sampling.

EMPIRICAL VALIDATION OF SYSTEMATIC SAMPLING

Conway (1) notes the practical advantages of fixed interval observations and offers a qualitative discussion of the problem in his paper on statistical considerations in work sampling. Haines (3) reports an empirical validation of systematic sampling with a two-minute interval, but does not explicitly define the analytical problem. The paper mentions a "basic assumption(s)" that "activities were random by nature, of varying lengths or durations, and generally *longer* (our italics) than the interval of observation." The meaning of "random by nature" is not specified, nor is it explained why the assumptions are "basic" or how, on practical grounds, they are justified. They are apparently used as a basis for inferring applicability of binomial distribution theory, for the binomial variance formula is employed in calculating

a confidence interval on the estimates of proportions obtained from fixed interval observations. In short, Haines treats the problem as though it were analogous to the random interval case.

ANALYTICAL FORMULATION

In attempting to give this problem an explicit analytical formulation we have come to the conclusion that it is not analogous to the random interval problem except under a special condition that will not prevail in all practical work sampling studies. At the same time it appears to us that there is an analytic model which is suitable under two other conditions that may be approximated to a satisfactorily high degree.

To develop our formulation of the problem we consider a process that is either in state A or A', and a sequence of instantaneous observations X_j, $(j = 1, 2, \ldots n)$, each taking place at the mid-point of an interval τ. We let $X_j = 1$ if the process is in state A at the jth observation. If we now define n_A as the total number of observations which found the process in state A, it is clear that

$$n_A = \sum_1^n X_j. \qquad \text{Eq. 1.}$$

The proportion of observations finding the process in state A will then be

$$p_A = \frac{n_A}{n} = \frac{1}{n} \sum_1^n X_j. \qquad \text{Eq. 2.}$$

This notation is illustrated in Figure 1. Our statistical problems arise when we ask ourselves what analytic model will enable an estimate of the sampling errors to which the quantity $n_{A/n}$ is subject. Will the binomial distribution model apply?

It is a necessary and sufficient condition for applicability of the binomial distribution model that:

$$E(X_1) = E(X_2) = \cdots = E(X_n). \qquad \text{Eq. 3.}$$

We know, of course, that this condition can be secured by randomization of observation times. In the case of systematic sampling, however, satisfaction of the condition implies:

$$\tau > A, A' \text{ for all } A \text{ and } A', \qquad \text{Eq. 4.}$$

for otherwise some X_j's are dependent upon preceding observations and Eq. 3. will not hold. This, of course, is contrary to Haines' assumption that "activities were . . . generally longer than the interval of observation."

It is conceivable that in some practical applications it will be feasible to satisfy condition Eq. 4., in which case the binomial variance formula is applicable to the estimation of sampling errors. In many instances, however, it may be that the sampling interval is most conveniently chosen, as in the studies reported by Haines, so that the following condition is approached:

$$\tau \leq A, A' \text{ for all } A \text{ and } A'. \qquad \text{Eq. 5.}$$

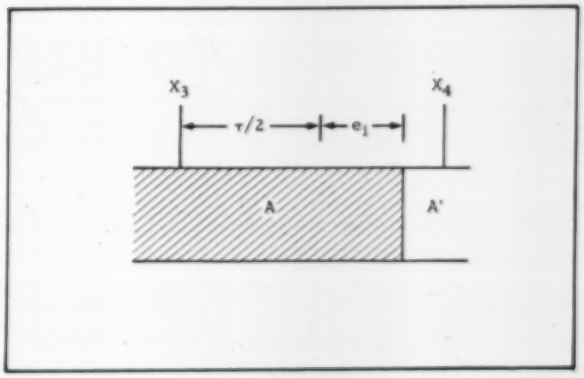

FIG. 2

Our problem then is to find an analytic model that is valid for estimation of sampling errors under this condition. We can in fact propose such a model if one additional condition is prescribed, namely:

$$P_{|e_{i-}y_|} = C, \text{ a constant}; \quad -\tau/2 \leq y \leq \tau/2, \qquad \text{Eq. 6.}$$

where e_i is defined as the time from the division point of the observation interval to the point at which the ith *change* of activity state occurs (Figure 2). We will also introduce the quantity $2N$ to designate the number of changes in activity state that occur during the n observations.[1] Condition Eq. 6. simply specifies that the *changes* in activity state occur at random with respect to the observation intervals. This is a reasonable expectation in conjunction with condition Eq. 5. and providing it is satisfied we shall not have to be concerned with nonrandomness in any other properties of the activities. This is an important feature, for we know that activities may be decidedly non-random in certain respects.

The problem as we have now defined it has an elementary and well known solution. It becomes obvious when we observe that the problem is analogous to that of rounding errors with randomly distributed terminal digits. The population of errors is rectangular (by condition Eq. 5.) with zero mean and variance $\tau^2/12$. By the definition of e_i it is apparent that the estimate of total duration, $n_A\tau$, of activity A will contain an error, ξ, that is the sum of $2N$ individual "rounding errors."

$$E(\xi) = E\left[\sum_{i=1}^{2N} e_i\right] = 0.$$

The distribution of ξ is given by Cramer (2), who shows that it "rapidly approaches" the normal distribution. Shewhart (4) cites experimental data which illustrate this fact. Thus for large N we may take ξ as normally

[1] In practice N is most easily determined by counting the number of separate occurrences of activity A; that is, the number of *sequences* of observations showing activity A in the set of n observations.

distributed with mean of zero and variance $\frac{2N\tau^2}{12}$.

It follows that the standard error of estimate for

$n_{A\tau}$ is $\tau\sqrt{\frac{N}{6}}$. And since $p_A = \frac{n_{A\tau} \pm \xi}{n\tau}$,

the standard error of estimate for p_A is $\frac{1}{n}\sqrt{\frac{N}{6}}$.

An interesting feature of this standard error is the fact that unlike the binomial standard error it is independent of p_A. Also, it is more sensitive to sample size, varying as $1/n$ instead of as $1/\sqrt{n}$.

Finally, it may be noted that systematic "sampling" with intervals smaller than the activity duration is fundamentally the same process as "measuring" with a stop watch.

SUMMARY

It has been our purpose in this discussion to present a more explicit formulation of sampling error estimation problems in systematic activity sampling than has heretofore been offered. This formulation directs attention to the requirement for observation intervals in excess of activity durations as a condition for strict applicability of binomial distribution theory. For an alternative case of observation interval equal to or less than the duration of activity states, our development demonstrates the applicability of a simple and well known model. While there will be occasions in practice when it will not be desirable to choose the observation interval so as to assure strict applicability of either model, it is likely that one or the other will provide a satisfactory approximation in most instances.

Where no condition can be assumed on the observation interval relative to activity duration, the analytic representation of sampling errors becomes difficult. It is possible to impose other conditions that make the problem soluble, but all of the conditions that we have examined thus far seem unrealistic for practical applications. At the moment, therefore, remarks on this case must be limited to the suggestion that the practitioner is no worse off than he has been in using the binomial variance formula without concern for the conditions of applicability. In our opinion one is unlikely to get into serious difficulty except through large bias errors, and these can probably be recognized by a practitioner who is familiar with the process under observation.

REFERENCES

(1) Conway, Richard W., "Some Statistical Considerations in Work Sampling," *The Journal of Industrial Engineering*, Vol. III, No. 2, March-April 1957.

(2) Cramer, C. H., *Mathematical Methods of Statistics*, Princeton University Press, 1946, Princeton, p. 245.

(3) Haines, I. Landis, "Work Sampling by Fixed Interval Study," *The Journal of Industrial Engineering*, Vol. IX, No. 4, July-August 1958.

(4) Shewhart, W. A. *Economic Control of Quality of Manufactured Products*, D. Van Nostrand Co., Inc., New York, 1931, p. 182.

(5) Tippett, L. H. C., "A Snap-Reading Method of Making Time-Studies of Machines and Operatives in Factory Surveys," *The Journal of The Textile Institute*, 1935, Feb., pp. 51-70.

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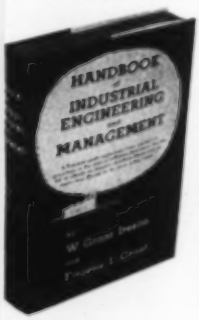

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Solution Methods for Waiting Line Problems[1]

by **JOHN R. SHELTON**

Chief, Operations Standards Division
The Port of New York Authority

MANAGEMENT problems commonly arise from business systems in which people, machines or materials form waiting lines for some type of servicing or processing. Different types of solution methods for these problems have been developed, varying according to the scope and complexity of waiting line system properties.

These types of problems are encountered by The Port of New York Authority in its operation of a diversity of public service facilities such as airports, tunnels and bridges, land and marine terminals. The manifold activities occurring at these facilities require some kind of service or processing for people, vehicles, equipment, and so forth.

It is the intent of the Port Authority management to furnish safe, efficient, and economical service in these waiting line activities. Some years ago the need for effective methods of analyzing waiting line problems was recognized and a pioneer effort was begun, using the various techniques associated with Operations Research.

As a result, the problem of waiting lines at toll booths at Port Authority bridge and tunnel facilities was subjected to scientific analysis by its Management Engineering group (6). Following the successful completion of this study project, many other areas were subjected to the same scientific analysis, such as motorized police patrols, elevator service, telephone and lobby information services and the like (7).

In the various study projects involving waiting line problems, much useful material was collected from widely scattered descriptions published in a variety of technical and management literature.

This article is an attempt to summarize general principles of waiting line system analysis and the application of appropriate solution methods. A collection of formulas and working curves is included covering a broad range of the more common problem types.

[1] This paper was developed by the Operations Standards Division, the Management Engineering group of the Port Authority. Special mention is made of Mr. Leslie C. Edie, Chief, Project and Planning Division for recognizing the value of such a compilation; and to Mr. Norman Jennings, Management Engineer, who developed the descriptive portions of this material and also researched the validity and applicability of all formulas.

DESCRIPTION OF WAITING LINE PROBLEMS AND SOLUTION METHODS

Waiting-line (queueing) systems create a major class of decision-making problems in the management of business activities. Waiting-line system problems occur whenever a flow of arriving traffic consisting of elements (people or things) establishes a variable demand for service at facilities of limited service capacity. Waiting time, or delay, (the time lapse between arrival and service to elements) varies inversely with the level of service capacity, i.e., the number of service stations (servers) and the rate of servicing maintained by each server. For example, in a supermarket, the higher the number of cashiers and the higher the cashiers' transaction rate, the shorter are patron waiting times.

Management's objective in these problems is to select a "best" of alternative system operating schemes, that is, one which maintains an economic balance between waiting times and service capacity. Meeting this objective for any queueing system requires a practical and effective analytical means of solution, i.e., of predicting delays produced at specified arrival and service capacity levels. As one would expect, difficulty in determining such a means of solution increases with the scope and complexity of various properties which distinguish different types of waiting-line systems.

Some of the important waiting-line system properties are as follows:

1. *The pattern of arrival rates of traffic elements*—Arrival rates during a period of system operation may be variable or constant. An average value of variable rates occurring during the period is useful in distinguishing among different levels of variable arrival rates. However, the range and frequencies of occurrence of variable arrival rates exert critical influence on variability in the lengths of waiting lines. The complete pattern of variable arrival rates must therefore be specified in distinctive numerical form. The arrivals pattern is explicitly defined in terms of a probability distribution of the different values of intervals between successive arrivals expected to occur during a specified period. The cumulative form of this distribution is commonly used for this purpose as a matter of analytical convenience. In many problem types this distribution can be described by a mathematical formula.

2. *The pattern of service (holding) times*—These times may be constant for all arriving elements or may vary. Where variable, probability distributions of service times must be specified. Common types of service time distributions can be conveniently expressed as mathematical formulas.

3. *Waiting line discipline*—Elements may be selected from the waiting line for service in the order of their arrival, completely at random, according to priorities, or on some other discriminative basis. In some cases elements may disappear after occupying waiting-line positions for some period of time; and in others arrivals will not wait at all.

4. *The quantity of servers*—Multiple-server waiting-line sys-

tems are more complex than single-server systems. Some problems arise in which the quantity of servers is so large (for all practical purposes, infinite) that waiting times are negligible and only the level of server occupancy is of analytical interest.

5. *The quantity of tandem service stages*—In many systems, such as the flow of parts or materials through production processes or messages through relay offices, elements are processed through a succession of service stages. Departure patterns from one stage become arrival patterns to an ensuing stage.

6. *The quantity of arrivals*—On the basis of this property, solution methods divide into two classes according to whether or not the maximum possible quantity of arrivals is limited. Problems in which the maximum possible quantity is sufficiently large (in excess of 100) qualify for unlimited arrivals methods. Formulas for both classes will be presented in this paper.

Solution methods will also vary due to:

The measures of system performance to be computed—The combined effects of probability distributions of varying arrival rates and service times in any waiting-line system result in probability distributions of various waiting times. As with arrivals and service times, the cumulative form of this distribution is the convenient mode of expression.

Quality of system performance for specified arrival-rate and service-time inputs can be expressed in terms of several different measures of the waiting time distribution. Examples of these measures are:

1. The average waiting time of all arrivals served.
2. The average waiting time of only those arrivals that wait for service.
3. The proportion of arrivals that must wait longer than some critical interval of time.

It is usually desirable to calculate a range of different values of waiting time distribution measures produced at various specified levels of system loading. System loading (see "u" in SYMBOLS,) is defined as the ratio of the level of arrival load to the level of service capacity obtained during any period of system operation.

Another measure of system performance that is likely to be of interest is the amount of idle service capacity at the various levels of system loading. Economics of system operation rest on the balance between idle capacity costs and waiting time costs.

Transient waiting-line system conditions—In many waiting-line system problems the same levels of arrival rates and service capacity are maintained during a specified period of system operation. In other problems one or both of these may vary from interval to interval during the period of operation. These variations result in the need to study a period of system operation as a sequential chain of transitional states of system loading.

During intervals when the system loading ratio remains less than unity, systems are said to be stable, or in statistical equilibrium, such that delays do not tend to become infinite. A ratio of unity or greater results in system instability because delays tend toward infinity. However, short intervals of unstable system load ratios are found to be tolerable.

SOLUTION METHOD TYPES

Waiting-line systems are classified according to combinations of distinguishing patterns of the foregoing properties. During the recent past various standard mathmatical formulas (models) have been developed for solving problems involving some special types of waiting-line systems. Types of problems too complex for use of these standard formulas can sometimes be solved through derivation of ad hoc formulas by empirical means.

Where formulas cannot be obtained a general solution method can be used which consists of direct-image simulation of queueing systems' time sequences of arrival and servicing activities. This latter method usually involves voluminous repetitive calculations that are best handled by electronic computer. A discussion of this simulation method and its application will be made later in this article.

STANDARD FORMULA METHODS

Choosing an appropriate solution method for a given queueing system begins with accumulation and analysis of data which adequately describe the system's properties. In order to determine whether one of the standard formulas developed for special queueing system types can be used, the data on a problem's properties must be tested for conformance with one of these types.

In the case of the arrivals pattern property, one which is common to many of the standard formula queueing system types is that defined by a Poisson formula. For a known *average* quantity of arrivals in a specified unit of time, this formula predicts the probability of obtaining various quantities of arrivals in the same unit of time.

A Poisson-type arrival pattern is also characterized by an exponential cumulative probability distribution of intervals between successive arrivals.

Similar analysis for the service time pattern property can be made for any queueing system. One pattern of service times common to many of the standard formula queueing types is also that described by the exponential curve.

In addition to arrival and service time patterns,[2] all other distinguishing properties defining a given queueing system must be determined before attempting to find a means of solution. Comparison can then be made with the counterpart distinguishing properties of the special queueing systems for which standard formulas are available.

Standard formulas are catalogued according to distinguishing properties of systems to which they apply. Within each standard type, formulas differ according to the measures of service to be calculated. Appropriate references are listed for each formula.

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[2] An extensive discussion of a variety of these patterns is given in (13).

SYMBOLS

a = average number of arrivals per unit of time.
h = mean servicing time (holding time).
w = mean waiting time of all arrivals.
m = mean waiting time of delayed arrivals.
n = number of arrivals present (both waiting and being served) at any given time.
s = number of servers.
u = servers occupancy ratio = ah/s.
σ = standard deviation of servicing (holding) time.
$P(n)$ = probability of n arrivals being present at any random time.
$P(\geqq n)$ = probability of at least n arrivals present at any random time.
t = unit of time.
$P > t/h$ = probability of a delay greater than t/h multiples of mean holding time.
$P > 0$ = probability of any delay (delay greater than 0).
L = mean number of waiting individuals among all individuals.
i = ordinal term number in a series of mathematical terms.
$\sum_{i=f}^{k}$ = summation of fth through kth terms in a series.
N = maximum quantity of arrivals when limited.
$C_n^N = N!/n!(N-n)!$

INDEX OF WAITING LINE FORMULAS

Note: All formulas apply to single service stage systems.

UNLIMITED ARRIVAL QUANTITIES (POISSON)

	Formula No.
Any Service Time Distribution	
Single Server	Eq. 1.-Eq. 3.
Exponential Service Time	
Single Server	Eq. 4.-Eq. 10.
"s" (Finite) Servers	Eq. 11-Eq. 17.
Infinite Servers	Eq. 18.-Eq. 20.
Constant Service Time	
Single Server	Eq. 21.-Eq. 25.
"s" (Finite) Servers	Eq. 26.-Eq. 30.

LIMITED ARRIVAL QUANTITIES (BINOMIAL)

Exponential Service Time	
Single Server	Eq. 31.-Eq. 36.
"s" (Finite) Servers	Eq. 37.-Eq. 42.
Infinite Servers	Eq. 43.

WAITING LINE FORMULAS

Note: All the formulas listed apply to waiting line systems with a single service stage and service in arrival order. Asterisked (*) formulas apply also in systems with service in random order.

TYPE I—UNLIMITED ARRIVAL QUANTITIES (POISSON ARRIVAL PATTERN)

Group 1. Any service time distribution. Single server.

Reference

Eq. 1. $P > 0 = u$ (11)

Eq. 2. $w = \left[\frac{uh}{2(1-u)}\right]\left[1 + \left(\frac{\sigma}{h}\right)^2\right]$ (11)

Eq. 3. $m = \frac{w}{(P>0)} = \frac{w}{u}$ (11)

Group 2. Exponential service time distribution

a. Single server

Eq. 4. $*P > 0 = u$ (9, p. 150)

Eq. 5. $P > (t/h) = ue^{(u-1)(t/h)}$ (9, p. 150)

Eq. 6. $P(n) = (1-u)(u)^n$ (9, p. 72)

Eq. 7. $P(\geqq n) = u^n$ (9, p. 72)

Eq. 8. $*w = \frac{h(P>0)}{(1-u)} = \frac{uh}{(1-u)}$ (9, p. 152)

Eq. 9. $*m = \frac{w}{(P>0)} = \frac{h}{(1-u)}$ (9, p. 73)

Eq. 10. $*L = \frac{m}{h} = \frac{1}{(1-u)}$ (9, p. 73)

b. "s" (finite) servers

Eq. 11. $$*P > 0 = \left[\frac{(su)^s}{s!(1-u)}\right] + \left[\sum_{i=0}^{s-1}\frac{(su)^i}{i!} + \frac{(su)^s}{s!(1-u)}\right]$$ (9, p. 150)

Eq. 12. $P > \left(\frac{t}{h}\right) = (P>0)(e)^{-s(1-u)(t/h)}$ (9, p. 150)

Eq. 13. $P(n) = [P>0]\left[\frac{s!(1-u)(su)^{n-s}}{n!}\right]$ For $n < s$ (9, p. 72)

$P(n) = [P>0][(1-u)(u)^{n-s}]$ For $n \geqq s$ (9, p. 72)

Eq. 14. $$P(\geqq n) = 1 - \left[\left(\frac{(P>0)(s!)(1-u)}{(su)^s}\right)\sum_{i=0}^{n-1}\frac{(su)^i}{i!}\right]$$ For $n < s$ (9, p. 72)

$P(\geqq n) = [P>0][(u)^{n-s}]$ For $n \geqq s$ (9, p. 72)

Eq. 15. $*w = h\frac{(P>0)}{s(1-u)}$ (9, p. 152)

(See Figure 1 for plotted curves of this formula.)

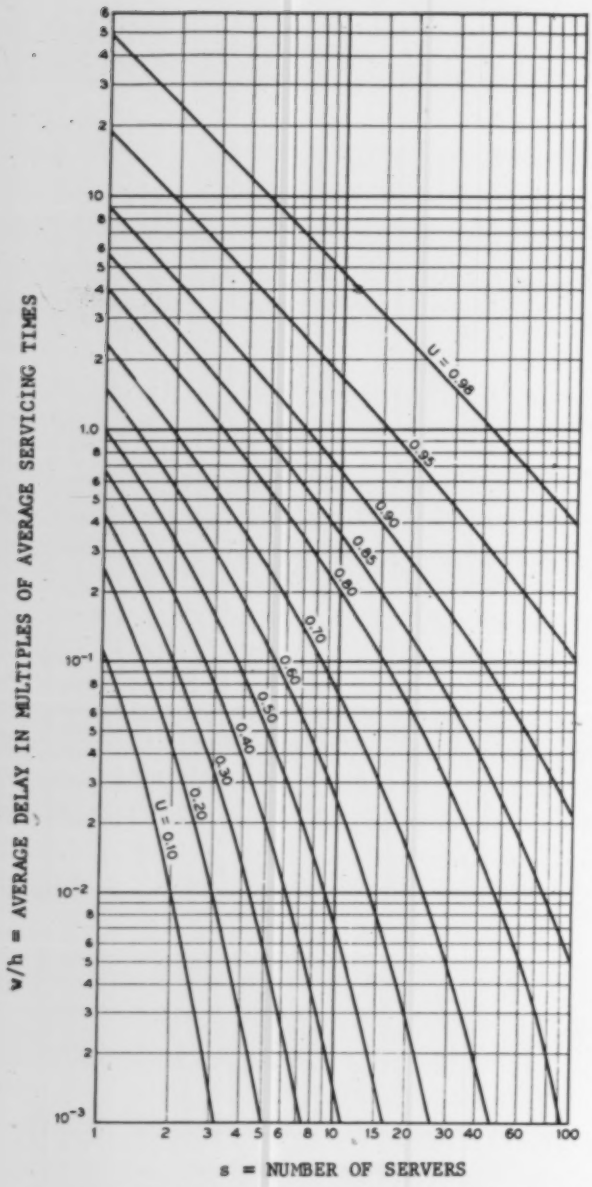

FIG. 1. Average Delay of All Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Exponential Service Times, Service in Random or Arrival Order (Eq. 15.).

Reference

c. Infinite servers

Eq. 18. $P > 0 = 0$

Eq. 19. $P(n) = \left[\dfrac{(ah)^n e^{-ah}}{n!}\right]$ (9, p. 36)

Eq. 20. $w = 0$

Group 3. Constant servicing time

a. Single server

Eq. 21. $P > 0 = u$ (9, p. 146)

Eq. 22. $P > (t/h) = 1 - e^{(ut/h)} + ue^{(ut/h)}$

For $0 < (t/h) < 1$ (9, p. 146)

$= 1 - e^{(ut/h)} + ue^{u(t/h-1)}$

$+ u(t/h - 1)e^{u(t/h-1)}$

$-u^2(t/h - 1)e^{u(t/h-1)}$

For $1 < (t/h) < 2$ (9, p. 146)

(See Figure 4 for plotted curves of the formulas and values for $(t/h) > 2$.)

Eq. 23. $w = \dfrac{(uh)}{2(1-u)}$ (9, p. 147)

Eq. 24. $m = \dfrac{w}{P > 0} = \dfrac{h}{2(1-u)}$ (2, p. 303)

Eq. 25. $L = \dfrac{m}{h} = \dfrac{1}{2(1-u)}$

b. "s" (finite) servers

Eq. 26. $P > 0 = 1 - \exp\left\{\left[-\sum_{i=1}^{\infty} \dfrac{e^{-sui}}{i}\right]\right.$

$\left.\left[\sum_{i=1}^{\infty} \dfrac{(sui)^{si}}{(si)!}\right]\right\}$ (5, p. 266)

(See Figures 5–10 for plotted curves of this formula.)

Eq. 27. $P > t/h$ (Formulas available are inconvenient. See curves in Figures 5–10.) (5, p. 266)

Eq. 28. $w = \sum_{i=1}^{\infty} e^{-sui}\left[\sum_{i=1}^{\infty} \dfrac{(sui)^{si}}{(si)!}\right.$

$\left. - \dfrac{1}{u}\sum_{i=2}^{\infty} \dfrac{(sui)^{si}}{(si)!}\right]$ (5, p. 266)

(See Figure 11 for plotted curves of this formula.)

Reference

Eq. 16. $^*m = \dfrac{w}{(P > 0)} = \dfrac{h}{s(1-u)}$ (9, p. 73)

Eq. 17. $^*L = \dfrac{sm}{h} = \dfrac{1}{(1-u)}$ (9, p. 73)

Eq. 29. $m = \dfrac{w}{(P > 0)}$ (2, p. 303)

Eq. 30. $L = \dfrac{ms}{h}$

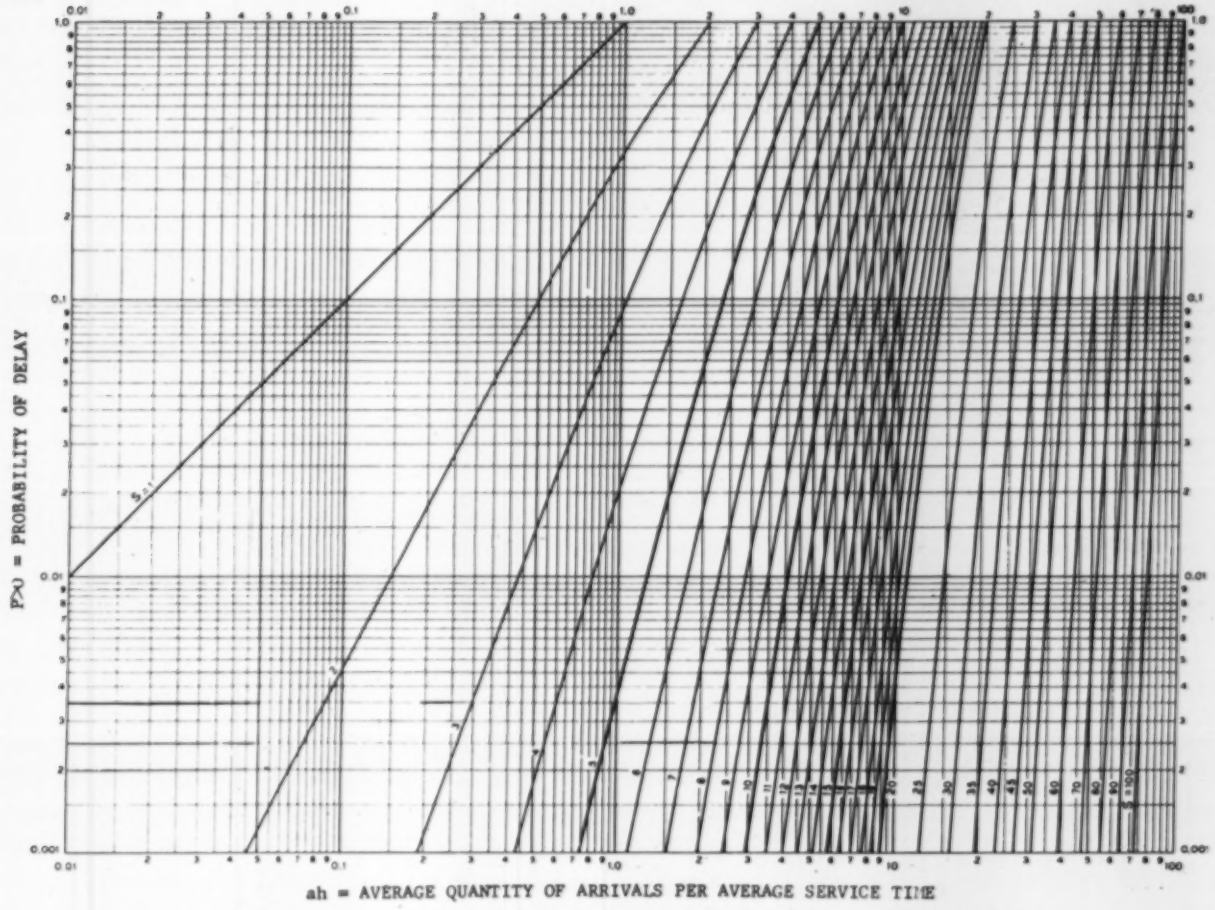

FIG. 2. Probability of Delay for Unlimited Poisson Arrivals Served in Random or Arrival Order with Exponential Service Times (Eq. 11.).

TYPE II—LIMITED QUANTITY OF ARRIVALS—N = MAXIMUM QUANTITY—(BINOMIAL PATTERN)

Exponential service time

Reference

a. Single server

Eq. 31. $$P(n) = \left[C_n^N u^n n!\right] \div \left[\sum_{n=0}^{N} n! C_n^N u^n\right]$$ (9, p. 74)

Eq. 32. $$P(\geqq n) = 1 - \left[\left(P(0)\right)\sum_{i=0}^{n-1} C_i^N u^i i!\right]$$ (9, pp. 72. 74)

Eq. 33 $$P > 0 = \sum_{n=2}^{N} P(n)$$ (9, pp. 73, 74)

Eq. 34. $$w = h \sum_{n=2}^{N} (n-1)P(n)$$ (9, pp. 73, 74)

Eq. 35. $$m = \frac{w}{(P > 0)}$$ (9, pp. 73, 74)

Reference

Eq. 36. $$L = \frac{m}{h}$$ (9, pp. 73, 74)

b. "s" (finite) servers

Eq. 37. $$P(n) = \frac{C_n^N (su)^n}{\left[\sum_{i=0}^{s} C_i^N (su)^i + \frac{C_i^N (su)^i i!}{s! s^{(i-s)}}\right]}$$

For $n \leqq s$ (9, p. 74)

$$P(n) = \frac{C_n^N (su)^n n!}{s! s^{(n-s)}\left[\sum_{i=0}^{s} C_i^N (su)^i + \frac{C_i^N (su)^i i!}{s! s^{(i-s)}}\right]}$$

For $s \leqq n \leqq N$

Eq. 38. $$P(\geqq n) = 1 - \left[\left(P(0)\right)\sum_{i=0}^{n-1} C_i^N (su)^i\right]$$

For $n \leqq s$ (9, pp. 72, 74)

Reference

$$P(\geqq n) = \left[\left(P(0)\right) \sum \frac{C_i^N (su)^i i!}{s! s^{(i-s)}}\right]$$

For $s \leqq n \leqq N$

Eq. 39. $P > 0 = \sum_{n=s+1}^{N} P(n)$ (9, pp. 73, 74)

Eq. 40. $w = \frac{h}{s} \sum_{n=s+1}^{N} (n - s)P(n)$ (9, pp. 73, 74)

Eq. 41. $m = \frac{w}{P > 0}$ (9, pp. 73, 74)

Eq. 42. $L = \frac{ms}{h}$ (9, pp. 73, 74)

c. Infinite servers

Eq. 43. $P(n) = C_n^N \left[\frac{su}{1 + su}\right]^n \left[\frac{1}{1 + su}\right]^{(N-n)}$ (9, p. 41)

USE OF WORKING CURVES

Most of the formulas for multi-server types of queueing problems are somewhat complex and cumbersome to use. For many of these types, values produced by some of their formulas over a range of different levels of system loading have been plotted in curve form for convient problem solution. Use of these curves[3] is illustrated in a few examples which follow.

Figure 1 yields w, mean waiting time of all arrivals for queueing system types with these properties:

1. Poisson Arrivals (Unlimited).
2. Exponential Holding Times.
3. Arrivals served in either random or arrival order.
4. s Servers.

Figure 2 yields $P > o$, the probability of having delay, for systems with the same properties as those in Figure 1. Figure 3 yields $F(z)$, a conditional probability value such that $[F(z)]\ [P > 0] = P > t/h$, the probability of exceeding a specified waiting time for system types with these properties:

1. Poisson Arrivals (Unlimited).
2. Exponential Holding Times.
3. Arrivals Served in Random Order.
4. s Servers.

To illustrate the use of Figures 1, 2, and 3 assume a given queueing system problem as follows:

[3] All curves included in this article apply to single service stage waiting line systems.

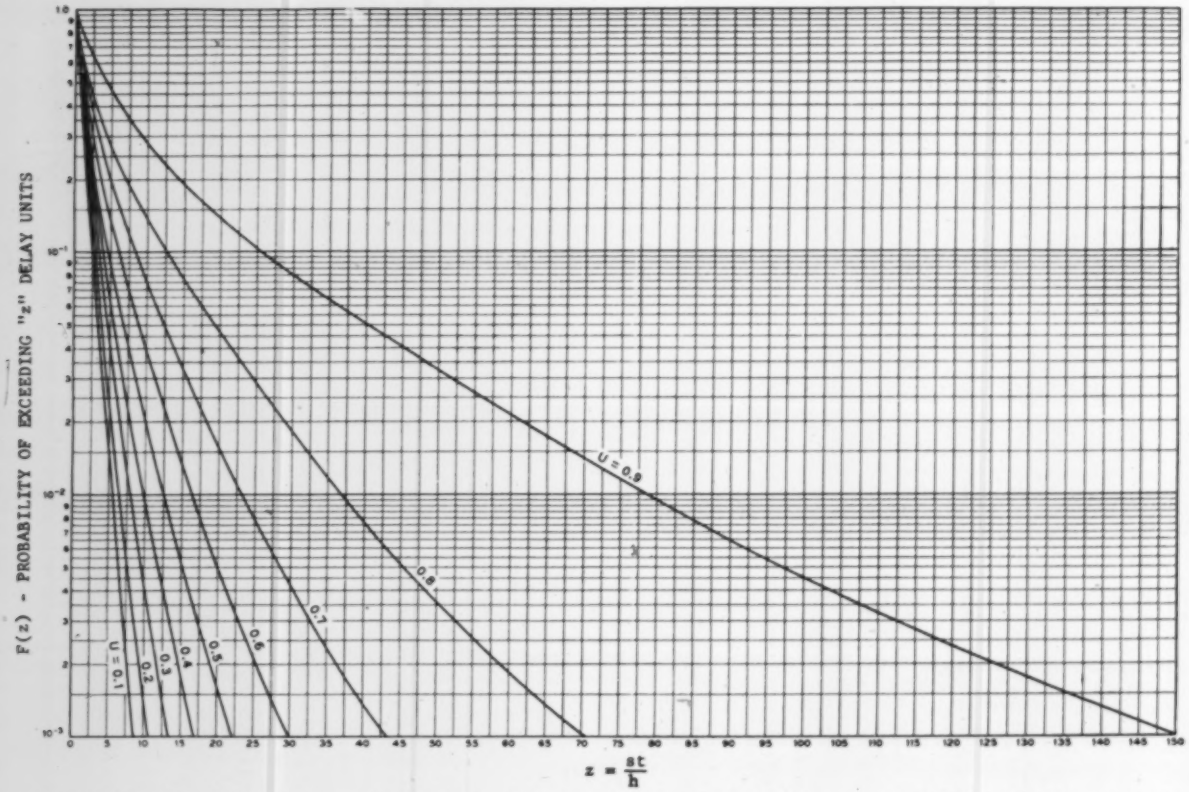

FIG. 3. Probability of Exceeding Specified Delays for Delayed Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Exponential Service Times, Service in Random Order (Curves Obtained from (16)).

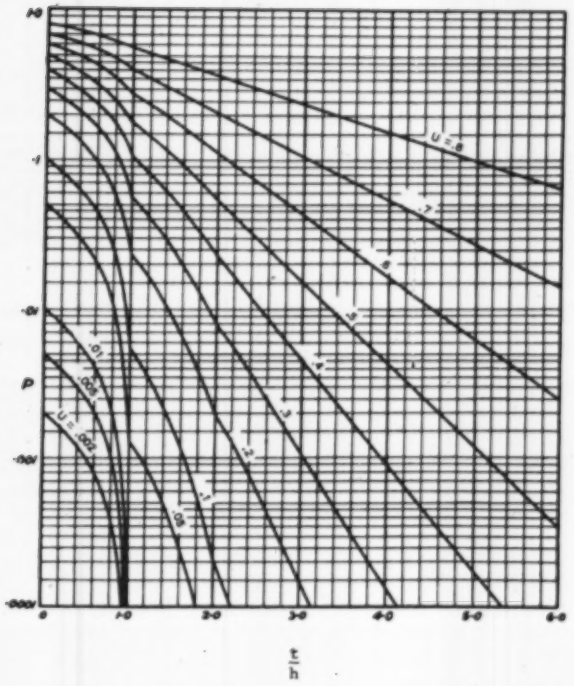

FIG. 4. Probability P, of Exceeding a Delay of t/h Service Times for All Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Constant Service Time, Service in Arrival Order, Number of Servers, $s = 1$ (Eq. 21. and Eq. 22.).

System Properties:

Poisson Arrivals (Unlimited), with $a = 5.4$ per min.
Exponential service times, with $h = 20$ secs.
Delayed arrivals served in random order.
Single queueing stage.
Two servers ($s = 2$).

Required:

1. Average Delay, w.
2. Probability of Delay, $P > 0$.
3. Probability of Exceeding 5 minutes delay, $P > 5$.

Solution:

1. Using Figure 1,

$$u = \frac{ah}{s} = \frac{(5.4)\left(\frac{20}{60}\right)}{2} = .9$$

The $u = .9$ curve intersects the $s = 2$ vertical line at the horizontal line $(w/h) = 4.25$; therefore $w = 4.25$, $h = (4.25)(20) = 85$ seconds.
This result can be checked by using Eq. 11. and Eq.15. as follows:

$$P > 0 = \frac{\left[\frac{[(2)(.9)]^2}{2!(1 - .9)}\right]}{[1 + (2)(.9)] + \left[\left(\frac{[(2)(.9)]^2}{2}\right)\left(\frac{1}{1 - .9}\right)\right]}$$

$$= \frac{16.2}{19} = .85 \qquad \text{Eq. 11.}$$

then,

$$w = \frac{20(.85)}{2(1 - .9)}$$

$$= 85 \text{ seconds} \qquad \text{Eq. 15.}$$

2. Using Figure 2

with $ah = 5.4 \times \frac{20}{60} = 1.8$,

and $s = 2$,

$P > 0 = .85$

This result checks with that in 1. above, using Formula 11.

3. Using Figure 3,

with $u = .9$

and $z = \frac{st}{h}$ (where $t = 5$ minutes)

$$= \frac{(2)(5)}{\left(\frac{20}{60}\right)} = 30$$

$F(z) = .08$

$P > 5 = (P > 0)[F(z)] = (.85)(.08) = .07$

Converse waiting line system problems arise which require calculating the quantity of servers sufficient to meet

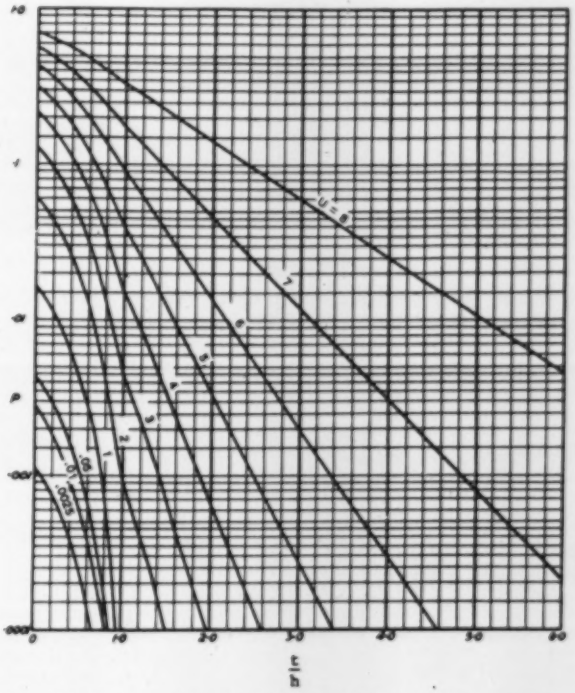

FIG. 5. Probability P, of Exceeding a Delay of t/h Service Times for All Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Constant Service Time, Service in Arrival Order, Number of Servers, $s = 2$ (Eq. 26. and Eq. 27.).

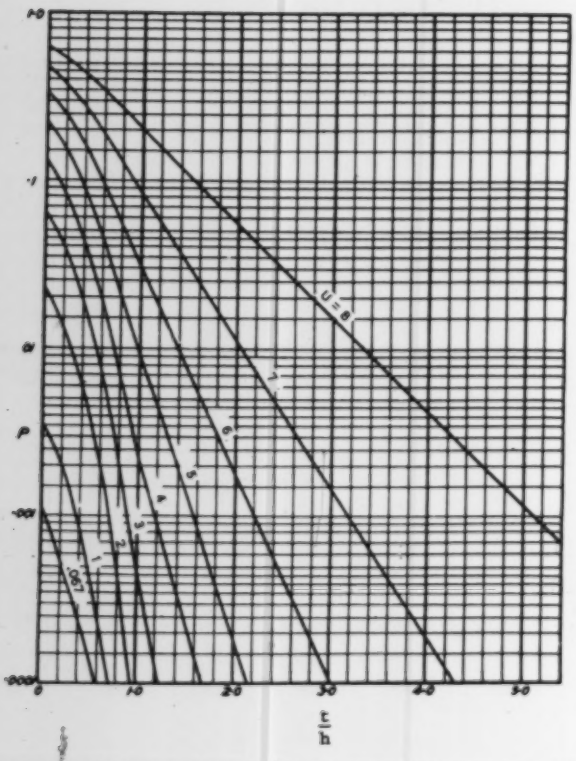

FIG. 6. Probability P, of Exceeding a Delay of t/h Service Times for All Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Constant Service Time, Service in Arrival Order, Number of Servers, $s = 3$ (Eq. 26. and Eq. 27.).

specified limiting values of average or maximum delay or both. For example, assume this problem:

System Properties:

Poisson arrivals (unlimited) with $a = 216$ per hour.
Exponential service times, with $h = 120$ secs.
Delayed arrivals served in random order.
Single queueing stage.

Service Criteria:

1. Average delay limit, $w = 45$ secs.
2. Maximum delay limit: no more than 5% of arrival to be delayed more than 4 mins.

Required:

Quantity of servers required to maintain the specified delay limits.

Solution:

1. Using Figure 1, with

$$ah = su = \left(\frac{216}{60}\right)\left(\frac{120}{60}\right) = 7.2$$

and $$\frac{w}{h} = \frac{45}{120} = .375,$$

Obtain these values of u for various numbers of servers:

s	u	su
7	0.81	5.7
8	0.83	6.6
9	0.84	7.6
10	0.86	8.6

It is apparent that 9 servers are the minimum required to maintain $w = 45$ secs.

2. Using Figure 2, with $ah = 7.2$

For 8 servers $P>0 = .70$
9 servers $P>0 = .45$
10 servers $P>0 = .25$

Using Figure 3, with $\frac{t}{h} = \frac{4(60)}{120} = 2,$

s	z	u	$F(z)$	$P>2 = (P>0)[F(z)]$
8	16	.90	.180	.126
9	18	.80	.055	.025
10	20	.72	.021	.005

It is apparent that with 9 servers only 2½ percent of all arrivals will be delayed 4 minutes or more. This more than satisfies the maximum delay limit criterion specified for the problem.

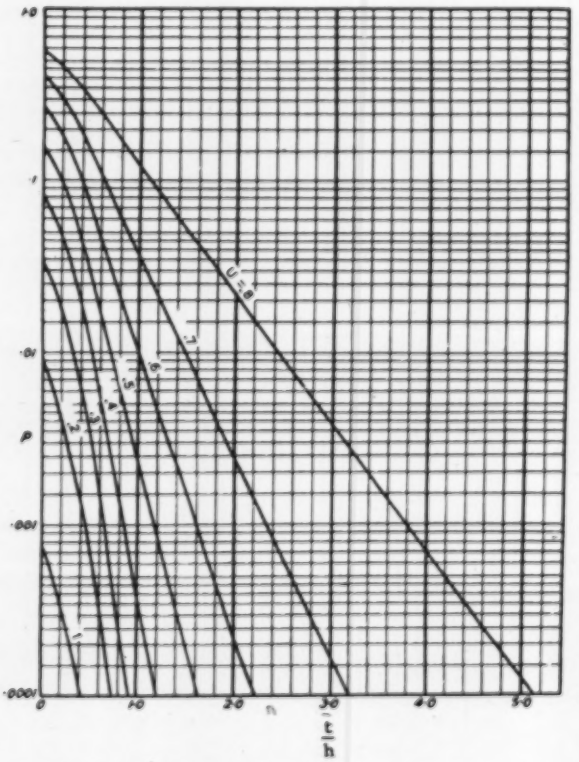

FIG. 7. Probability P, of Exceeding a Delay of t/h Service Times for All Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Constant Service Time, Service in Arrival Order, Number of Servers, $s = 4$ (Eq. 26. and Eq. 27.).

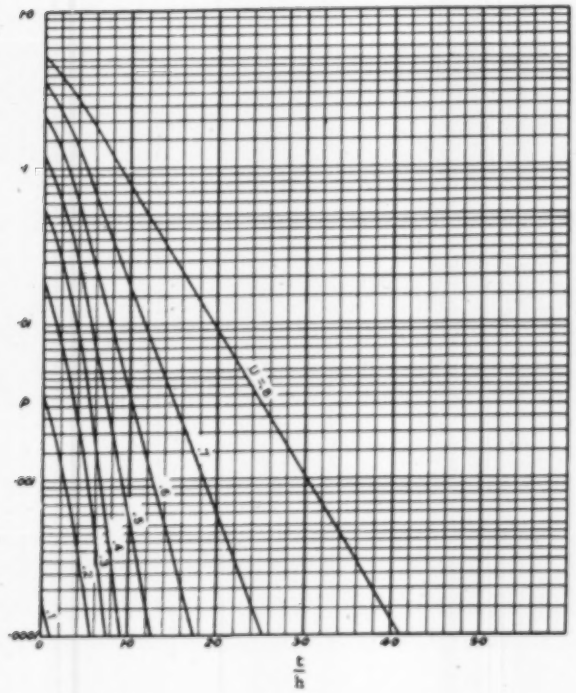

FIG. 8. Probability P, of Exceeding a Delay of t/h Service Times for All Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Constant Service Time, Service in Arrival Order, Number of Servers, $s = 5$ (Eq. 26. and Eq. 27.).

A set of curves useful for similar calculations in waiting line system problems characterized by *constant* servicing items is presented in Figures 4 through 11.

Figures 12 and 13 contain curves developed in (8). They are of particular interest in showing delays incurred during periods of a single-server system operation under transient and various *unstable* load conditions.

Formulas and curves applicable to a variety of other types of queueing systems are provided in various publications. Comprehensive lists of these publications are found in (11) and (12).

While many problems arise in which system properties conform adequately[4] to the standard model types, many more problems arise in which properties differ significantly from the standard types.[5] In some instances of these non-standard types it is often possible to develop suitable ad hoc formulas empirically from mathematical relationships to variables exhibited in problems' recorded data. An example of a multi-server system where this type of analysis was effectively used is the study of traffic delays at Port of New York Authority toll booths (6).

[4] Standard techniques for testing degree of conformance of distribution patterns are found in sections on curve fitting in statistical analysis literature.

[5] A discussion of analyses of some types of problem variations is found in (13).

THE SIMULATION METHOD

In the case of problems for which neither standard nor empirical formulas are obtainable the genera! method of simulation is appropriate. This method consists of creating a model of a queueing system in the form of a series of simple numerical statements. These statements comprise a direct-image of the flow-sequence of events characterizing operation of a waiting-line system.

To illustrate the direct-image simulation method Figure 14 shows the logical flow-sequence structure of a model for a typical simple single-stage queueing system. It will be noted that the model is basically a cycle of functional steps and decision rules which are followed in each time interval of a period of waiting-line system operation.

Each simulated period of system operation is developed using a sample set of input values drawn from specified arrival and service time distributions. This input set generates a sample output distribution of waiting line results for the period. The degree of variation among input samples and the degree of accuracy required in final results determine how many periods of a specified

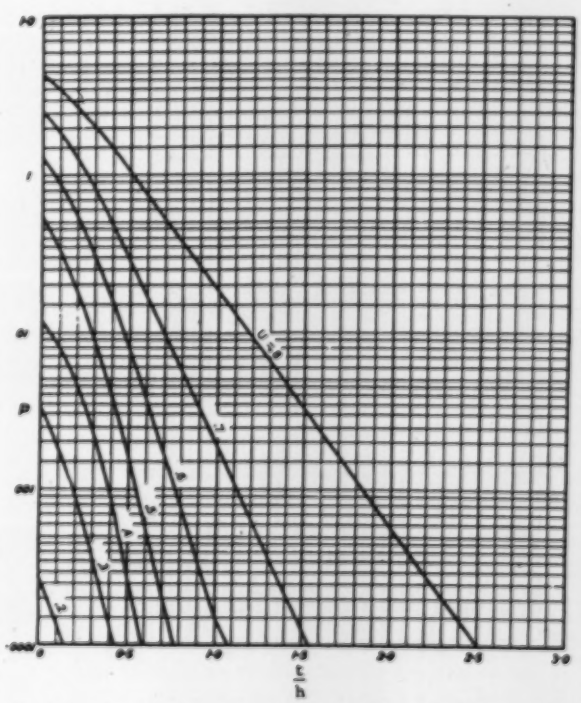

FIG. 9. Probability P, of Exceeding a Delay of t/h Service Times for All Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Constant Service Time, Service in Arrival Order, Number of Servers, $s = 8$ (Eq. 26. and Eq. 27.).

waiting line system operation must be simulated. This sampling procedure is often referred to as "Monte Carlo."

One of the most striking advantages of the simulation method is the analytical flexibility it affords. Operating results can be generated for any variety of patterns of arrivals, service capacities, waiting line disciplines, functional flow sequences and decision-making rules.

The direct-image simulation model therefore permits controlled experimentation with an unlimited number of different combinations of waiting-line system properties. In this manner, the effectiveness of many alternative modes of waiting-line system operation can be compared. It averts disruption of normal service and prohibitive costs that would result from similar experimentation in the actual system operation.

The versatility of simulation is most efficiently useful in problems involving systems having complex, lengthy flow sequence structures—particularly those with tandem service stages—and many probabilistic variables. A wide diversity of business, industrial and public service activities have such structures and constitute fertile problems for the application of simulation analysis.

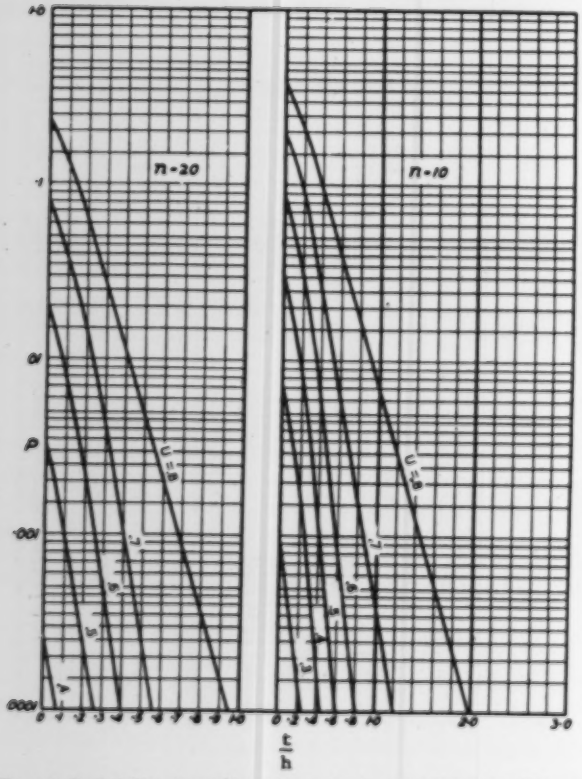

FIG. 10. Probability P, of Exceeding a Delay of t/h Service Times for All Arrivals in a Waiting Line System with: Unlimited Poisson Arrivals, Constant Service Time, Service in Arrival Order, Number of Servers, $s = 10$ and 20 (Eq. 26. and Eq. 27.).

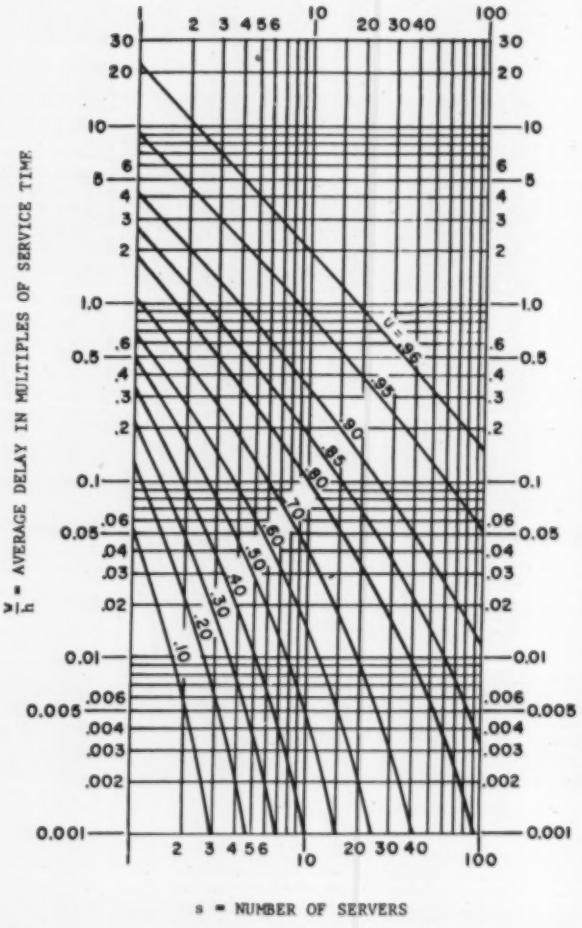

FIG. 11. Average Delays on All Arrivals in a Waiting Line System with These Properties: Poisson (Unlimited) Arrivals, Constant Service Time, Service in Arrival Order (Eq. 28.).

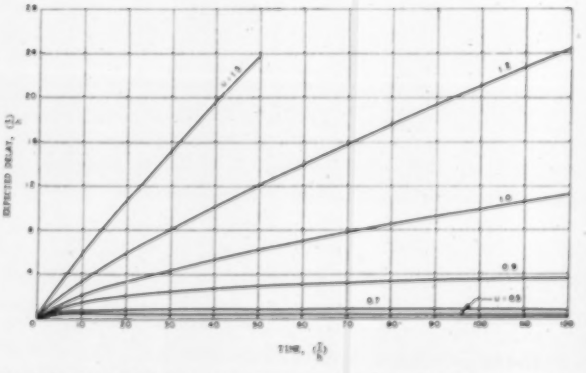

FIG. 12. Expected Delay of Arrivals at Time (T/h) for Several System Load Ratios and These System Properties: Poisson (Unlimited) Arrivals, Constant Service Time, Service in Order of Arrival, Single Server (Curves Obtained from (6)).

Several illustrative case studies of complex systems and their references are as follows:

Maritime Cargo Handling (14)
Open Hearth Furnace Operation (4)
Peak Hour Commuter Bus Operation (10)
Job Shop Production Scheduling (15)
Communication Network Traffic Flow (3)
Airline Maintenance (1)

Even in cases where mathematical formulas have been developed the simulation method proves invaluable as a practical means of checking applicability of the formulas.

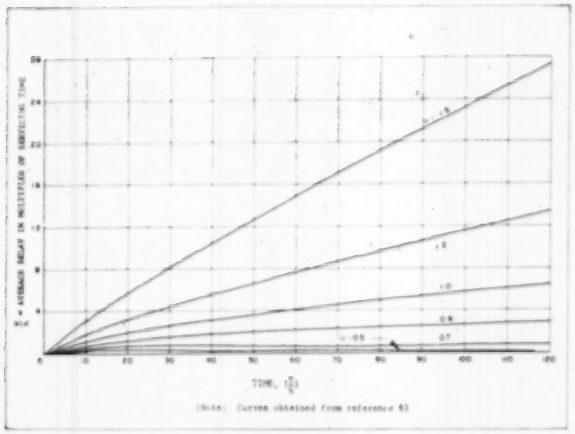

FIG. 13. Average Delay of All Arrivals During a Period of Operation under Various System Load Ratios with These Properties: Poisson (Unlimited) Arrivals, Constant Service Time, Service in Order of Arrival, Single Server (Curves Obtained from (6)).

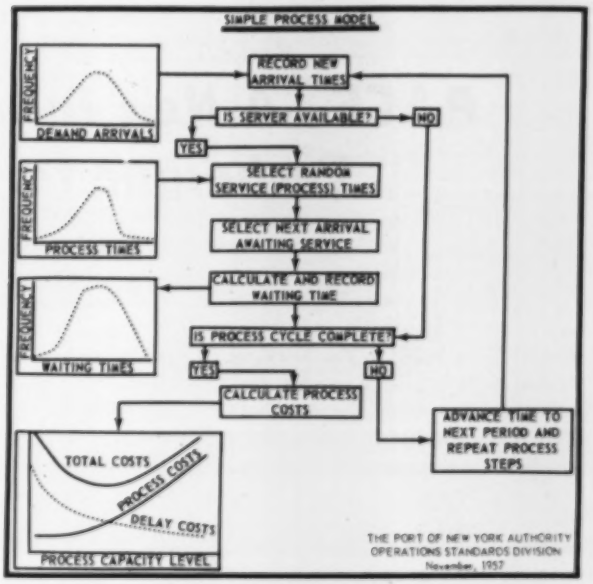

FIG. 14. Waiting Line Process Simulation.

REFERENCES

(1) ALBERTS, W. E., "Systems Simulation," *Proceedings of the Seventh AIIE Annual National Conference*, May 17-18, 1956.

(2) BERKELEY, G. S., *Traffic and Trunking Principles in Automatic Telephony*, Ernest Benn, Limited, London, 1949.

(3) BROTMAN, LEWIS, AND MINKER, JACK, "Digital Simulation of Complex Traffic Problems in Communications Systems," *Journal of the Operations Research Society of America*, October, 1957, Vol. 5, No. 5.

(4) CALHOUN, S. REED, AND GREEN, PAUL E., "Simulation: Versatile Aid to Decision Making," *Advanced Management*, April, 1958, Vol. 23, No. 4.

(5) CROMMELIN, C. D., "Delay Probability Formulae," *P.O.E.E. Journal*, January, 1934.

(6) EDIE, LESLIE C., "Traffic Delays at Toll Booths," *Journal of the Operations Research Society of America*, Vol. 2, No. 2, May, 1954.

(7) EDIE, LESLIE C., "Operations Research in a Public Corporation," *Journal of the Operations Research Society of America*, Vol. 2, No. 2, February, 1957.

(8) FRITZ, E., "Transient versus Steady State Delays in Airport Traffic," paper presented before American Statistical Association, New York University, May 27, 1955.

(9) JANSEN, ARNE, "The Life and Works of A. K. Erlang," *Transactions, Danish Academy of Science*, No. 2 (1948).

(10) JENNINGS, NORMAN H., AND DICKINS, JUSTIN H., "Computer Simulation of Peak Hour Operations in a Bus Terminal," *Management Science*, October, 1958.

(11) KENDALL, DAVID G., "Some Problems in the Theory of Queues," *Journal of the Royal Statistical Society*, Series B, Vol. XIII, No. 2 (1951), pp. 151-185.

(12) KENDALL, DAVID G., "Stochastic Processes Occurring in the Theory of Queues and Their Analysis by the Method of the Imbedded Markov Chain," *The Annals of Mathematical Statistics*, Vol. 24, No. 3, September, 1953, pp. 338-354.

(13) MORSE, PHILIP M., *Queues, Inventories and Maintenance*, John Wiley and Sons, New York, 1958.

(14) O'NEILL, RUSSELL R., "An Engineering Analysis of Cargo Handling," Report 56-37, September, 1956, Department of Engineering, University of California, Los Angeles, California.

(15) ROWE, ALAN J., "Computer Simulation Applied to Job Shop Scheduling," Report of System Simulation Symposium, Eighth National Convention of the AIIE, New York, May 16, 17, 1957.

(16) WILKINSON, ROGER I., "Working Curves for Delayed Exponential Calls Served in Random Order," *Bell System Technical Journal*, Vol. XXXII, No. 2, March, 1953.

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PACE—A New Industrial Engineering Technique for Management*

by **D. N. PETERSEN**

Chief, Manufacturing Methods Engineering, Norair Division, Northrop Corporation

EARLY in 1958 at the Northrop Corporation, a new management approach to improved productivity and cost reduction—the Pace Program—was successfully developed and established in the Norair Division. PACE—which is the acronym for Performance And Cost Evaluation—is a thoroughly proven, inexpensive, analytical statistical system for measuring group effectiveness in performing an assigned task.

In former years, most experienced manufacturing and production executives could fairly accurately determine the pace or tempo of factory operations merely by listening to the hum of activity in their particular shop or factory. In the heavily automated industries of today, however, this tempo is now largely established and maintained by machines and assembly line techniques, and the aforementioned rule of thumb measurement can no longer be applied. Instead, more exotic forms of measuring human endeavor, with all of its attendant complexities and intangible factors, had to be developed. Through this development, such manufacturing methods measuring devices as Time and Motion Studies and Time Delay Ratio Studies became increasingly more prevalent and were put into operation. In application, these manufacturing methods devices did what they were intended to do; namely, that of accurately evaluating individual human effort. Moreover, these manufacturing methods measuring devices were exceedingly costly to apply and maintain.

At present, the complexities of modern Weapon Systems and the rapidly expanding scope of their functional capabilities have challenged the ingenuity of the Engineering and Production forces within the airframe industry to a degree never before encountered.

Actually, the perfecting of technological solutions is, to say the least, momentarily gratifying. However, the accomplishment and transformation of these technological solutions into hard products of functional reliability have resulted in mounting costs that, cumulatively, have a severe impact upon the national economy. Parenthetically, this economic condition has imposed upon the management of airframe companies a grave responsibility in which the effective control of costs has assumed a role of importance equal to the functional capability and reliability of their products.

Unlike the heavily automated industries previously noted, the airframe industries have little or no assembly line methods with which to establish and maintain tempo. In aircraft and missile production, therefore, this establishment of tempo depends a great deal on the performance of people, with all of the complex and intangible factors that are inherently associated with human endeavor.

Northrop management, which has long been attuned to the tempo of people at work, reasoned that there must be an accurate way to measure and record this tempo—to determine when, where, and to what degree it fluctuates and why. If this could be accomplished, management felt it would then have a new tool; a *now* type of measurement which would pinpoint lost effort and pave the way for almost instantaneous remedial action.

As a result of this reasoning, Northrop now has this new management tool in the form of a unique PACE Program which was developed and established by the Manufacturing Methods Engineering organization. As stated in the Northrop Aircraft, Incorporated Annual Report for the fiscal year ended July 31, 1958, "Compared with presently established standards in the manufacturing organization, the PACE Program contributed a 21 percent improvement in group effectiveness during the first six months of its application."

This, then, is how the PACE Program was born and brought to fruition. At this point, you might justifiably ask: Just what is PACE and what does it do?

Broadly speaking, PACE can be broken down into two separate and distinct sections: one section is devoted to PACE Measurement; and the other section encompasses the PACE Program in its entirety.

PACE Measurement is a study of the effectiveness with which groups of individuals apply themselves. The PACE Program is PACE Measurement plus a comparative analysis of total performance of a group of individuals in accomplishing an assigned task. This comparative analysis is accomplished through the correlation of such other industrial control indices as: personnel requirements; budget realization; scheduling; quality con-

* Based upon a presentation to the Third Annual Industrial Engineering Seminar, Great Salt Lake Chapter AIIE, April 1959.

trol; and parts shortages. All of these indices, plus PACE Measurement, are then superimposed on a single frame of reference.

Therefore, since PACE is a statistical method of measuring current group effectiveness in performing an assigned task, the PACE Program provides daily measurement of group activities which are graded and reported upon. This measurement provides an immediate evaluation of departmental performance in the deployment and the effectiveness of group effort.

The results of Pace Measurement enable departmental supervision to determine immediately the scope of corrective measures required. Through intelligent interpretation of this information, additional improvement in productivity and cost reduction can be realized. In cases of low PACE ratings, additional methods engineering studies can be requested by line supervision or organizational management to determine the basic causes and provide immediate remedial action.

The most important single aspect of the PACE Program is its value in spotting defective areas immediately and bringing these facts to the attention of the appropriate supervision and management in any manufacturing organization.

The next portion of this discussion will describe how PACE Measurement, PACE observation, and PACE evaluation are accomplished for manufacturing functions. Still later in this discussion, the manner in which the PACE Program comparative analyses are achieved will be more fully explained. It should be noted at this point that though considerable reference is made to the aircraft industry in this discussion, it is made strictly for the sake of comparison. The PACE Program (with minor modifications) can be readily applied to any organization in which performance and production are not geared to either heavy automation or rigid assembly line techniques. Figure 1 illustrates the areas of potential savings that can be realized through the establishment of the PACE Program.

PACE MEASUREMENT

The initial step required to achieve the basic objectives of the PACE Program was to establish a basis for sound measurement of group effort. The measurement process had to be both inexpensive and simple to apply. Additionally, the measurement process had to be applicable through all phases of production and reflect the composite effects of all factors contributing to deviations from planned performance.

After careful consideration, Northrop's manufacturing methods engineers determined that there were four prime factors which had a direct effect on group effectiveness. The four factors are:

1. The number of people available to work—the number assigned, plus or minus loans.
2. The average effort of those people who are working—Group Effort Rating.

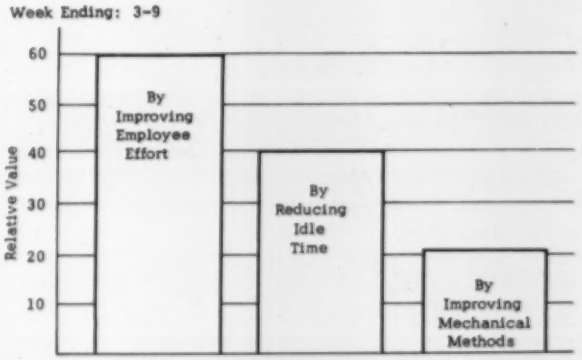

FIG. 1. Areas of Potential Savings.

3. The number of people idle—Idle Time.
4. The number of people not in the assigned work area—Out of Area.

NUMBER ASSIGNED, PLUS OR MINUS LOANS

In the measurement of group effectiveness, it is important to know exactly how many individuals are available to do the work at any given time. The number of individuals assigned to an organization, plus or minus the number of individuals loaned into or out of that organization, comprise the number of individuals available to accomplish the assigned task.

GROUP EFFORT RATING

Since the PACE formula was intended to be used in the measurement of group effectiveness, a factor new in the field of Industrial Engineering had to be developed. This new factor was the group effort rating.

Effort rating of individuals is an established practice for which there exist many Industrial Engineering techniques and standards. To convert from individual rating to composite group rating, Norhtrop's manufacturing methods engineers evolved a system by which a value could be assigned to the composite effort of those working. Using Industrial Engineering techniques to establish effort standards, the group effort rating is the measure of deviation from standard expectancy of those actively working. For example: take a group of five individuals engaged in the manufacture of a piece of equipment and assign an effort rating to each individual. In this case, let's apply a rating of 100% to the first, 50% to the second, 105% to the third, 60% to the fourth, and 75% to the fifth person. The sum total of these ratings is 390%. Divided by 5, the result is 78%. This, then, is the composite group effort rate.

IDLE TIME

In PACE Measurement, two types of idle time are observed and evaluated. One type is the obvious idle time (in which individuals are obviously not expending effort in the performance of an assigned task). The other

type is the hidden idle time (in which individuals are actively engaged but are not contributing to the completion of the assigned task).

OUT OF AREA

PACE Measurement also observes and evaluates two types of out of area time. A definite distinction is made between out of area time which directly contributes to the accomplishment of the assigned task of a group, and out of area time which does not. Time spent out of the area by an individual directly contributing to the group effort will not affect the results of the PACE formula. Generally, time spent out of the area by an individual not contributing to the group effort will affect the PACE formula. Let's take the hypothetical case of Little Joe for example: When he is working at his assigned task, he naturally is not out of the area. However, should Little Joe decide to go to the storage area for a part he requires in his work and does this in direct opposition to standard practices established by his supervision, he is definitely not contributing to his assigned task, and therefore, his contribution to group effectiveness in accomplishing an assigned task is penalized by his unauthorized out of area activity. Other similar unassigned out of area conditions which could penalize Little Joe's group effort rating include: unauthorized trips to engineering; trips to industrial relations; and out of area on personal business. One out of area condition which does not affect the group effort rating is when Little Joe is officially authorized to perform an assigned task at some other geographical location in the plant.

PACE FORMULA

By combining these four factors—the number of individuals assigned plus or minus loans, group effort, number of individuals observed idle, and the number of individuals observed out of area—Northrop's manufacturing methods engineers developed a working hypothesis which, after considerable testing in a variety of actual operations, became the PACE formula that is applied for manufacturing observation and evaluation. This is the PACE formula:

$$\frac{[\text{No. Assigned} \pm \text{Loan} - (\text{Idle} + \text{Out of Area})] \times \text{Effort Rate}}{\text{No. Assigned} \pm \text{Loans}} \times 100 = \% \text{ PACE}$$

In the PACE Measurement formula, the denominator represents the number of individuals available for work. Between the large brackets of the numerator is the number of individuals actually working at any given time. This latter quantity, multiplied by a group effort rating, determines the equivalent number performing the work of the group. The resultant quantity of the expression is then multiplied by 100 to convert to a percentage value, which is the PACE of the group. Therefore, PACE Measurement is an evaluation of group effectiveness in performing an assigned task.

PACE OBSERVATION

To provide uniform and effective PACE Measurement, the contingent step of PACE observation must be conducted with a high degree of professional competence. A trained observer can measure the group effort of over 400 people per day. The nucleus of the PACE observer staff, therefore, is a group of highly skilled professional individuals with extensive backgrounds in Industrial Engineering. The professional and analytical capabilities of these specially selected observers contribute to the continued development of the observation techniques and methods which are so vital to the successful application of PACE Measurement. In the specific area of group effort rating, considerable comprehensive training is required to develop the observer staff from the point of rating a single individual through rating the effort of several individuals and, finally, to rating the cumulative effort of a composite group.

As the trained PACE observer screens a work group, he must determine:

1. The number of individuals assigned, plus or minus loans.
2. Group effort rating.
3. The number of individuals idle.
4. The number of individuals out of area.

The frequency and type of PACE observations entail the Industrial Engineering technique of random sampling in accordance with sound statistical principles whereby the observations are accomplished at random times and over different routes. The number of individuals observed idle and the number of individuals observed working are determined through the simple means of using a Veedor-Root counter. The number of individuals out of area is determined by deducting the total observed from the assigned enrollment in the particular organization under observation.

The group effort rating, which is the most complex determination, is based upon the Industrial Engineering capabilities of the observer and his evaluation of all factors subject to consideration. It should be emphasized here that this group effort rating constant is determined only by the summated evaluation of those individuals working; idle individuals are not considered for this determination.

APPLYING PACE MEASUREMENT TO A BASIC REPORT

Using the PACE formula, the qualified observer can establish the group PACE rate. The PACE rating percentage, the effort rating percentage, the percentage of idle time, and the out of area percentage can then be charted for a basic PACE report as illustrated in Figure 2. The PACE rating percentage is achieved by considering the composite effects of the other three percentages.

As weekly PACE Measurements are added to the basic PACE report, it becomes possible to trace the trend of each of the PACE factors. The direction and rate of change of these trends are the important areas to analyze. Normal week to week fluctuations of these factors are expected, due to external influences.

USE OF PACE MEASUREMENT

The following theoretical case in point illustrates the use of PACE Measurement. In theory, a department with one hundred employees—in which 3 percent of the employees were observed out of area, 15 percent idle time observed within the department, and 75 percent as the group effort or PACE of the working employees was observed—would be able to accomplish the same amount of work with sixty-two employees if the preceding conditions were corrected.

PERFORMANCE TARGETS

The next step in the application of PACE Measurement is to establish the desired performance targets. On a basic PACE report chart similar to the chart illustrated in Figure 2, the target for the group PACE rating is placed between the 85th and 100th percentiles. On the same report chart, the target for idle time and out of area indications is placed in the zone immediately below the 5th percentile. These zones represent the areas of initial target performance and are called control areas. For practical considerations, PACE cannot be expected to improve overnight to meet these performance target areas. Therefore, during the early weeks of PACE Measurement, an initial improvement target for group PACE can be established by extending two converging lines at an angle into the 85th to 100th percentile zone. Considering the psychological changes which must come about before improvement can be realized, this target corridor should be only as steep as is practically feasible. This initial improvement area is called a target corridor and is illustrated later in this dissertation in Figure 4.

Through careful analysis of the direction and rate of change of the PACE trend line, therefore, the existence of a problem area immediately becomes obvious. This permits application of remedial action to be initiated at an early date.

PACE MEASUREMENT PHASING

Considering the application of PACE Measurement to a group, it is necessary to establish the sequence in which phases of the study occur. This is accomplished in four phases:

1. Indoctrination Phase.
2. Preliminary Measurement Phase.
3. Routine Observation Phase.
4. Periodic Program Review with Management.

The Indoctrination Phase takes place following a request from management to establish PACE observation

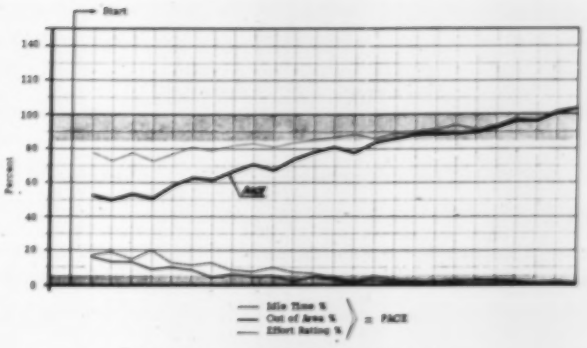

Fig. 2. Basic PACE Report Chart.

in a department or group of departments. Management and supervision of these departments are then briefed on the concepts and details of the PACE Program.

The Preliminary Measurement Phase is broken down into two operations. During the basic development week a PACE technician and permanent PACE observer are assigned to the department concerned. The technician and observer become acquainted with supervision in the various areas in which they are to function; they become acquainted with the work functions in these particular areas; and they develop the observational techniques for those work functions. The technician and observer then conduct trial random samplings to verify these observational techniques. During the basic study week, the PACE technician and permanent PACE observer study the group at random fifteen times per day for an entire week. This basic study establishes the conditions existing in the department at the time that the PACE Program is initiated. This basic study also serves as a basis for comparing and evaluating future PACE performance.

The Routine Observation Phase encompasses: routine daily observations and calculations at random periods; a weekly PACE report, encompassing the results of these observations and calculations; a weekly analytical report, providing descriptions and analyses of problems with suggested solutions; and weekly conferences with management to provide results and recommend methods to improve performance.

The Periodic Program Review with Management phase entails further conferences with management to provide even more detailed analyses of problems and recommended remedies as well as establishing newer and better observational methods and techniques.

Figure 3 illustrates a typical manufacturing methods PACE Program organization chart.

TRANSFORMING PACE MEASUREMENT INTO AN EFFECTIVE PACE PROGRAM

The preceding discussion has illustrated the development and establishment of PACE Measurement and Pace observational methods and techniques; the remainder of this discourse deals with the transformation

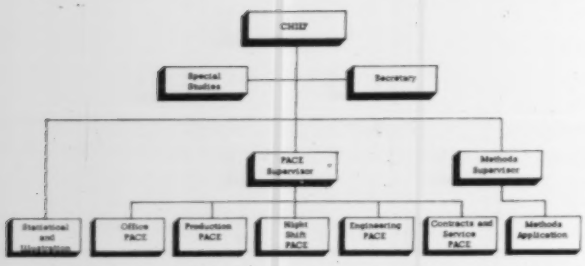

FIG. 3. Typical PACE Program Organization Chart (Manufacturing Methods Engineering).

of Pace Measurement into an effective PACE Program.

As previously noted, the PACE Program is PACE Measurement plus a comparative analysis of total performance of a group in accomplishing an assigned task. At Northrop, there are five standard measures of performance currently in use. These measures of performance include: personnel required, budget realization, schedules, quality level, and top priority shortages. Parenthetically, it should be noted that not all manufacturing organizations utilize all five of these measures of performance indices. In many instances, as few as one or two or as many as three or four might be used. In order to use these measures of performance on a basic PACE rating report, it was necessary to adapt them to the PACE report by converting the measures of performance into percentage values. These percentage values are called indices.

Essentially, the PACE Program entails a superimposition of all available indices of performance of a group in the accomplishment of an assigned task onto the basic PACE rating report. A graphic comparison of these indices can then be accomplished. In this way, the PACE Program can provide management with cost and performance yardsticks blended into a comprehensive and easily understood single frame of reference.

When incorporated into the PACE Program, these performance indices have a direct as well as an interdependent relationship with the group PACE rating. To illustrate this point more accurately, the characteristics of each of these five measures of performance indices that could be used in conjunction with the PACE Measurement indices in a PACE rating report should be examined in greater detail.

Prior to entering into a dissertation on the measures of performance, however, the techniques used in establishing the PACE Measurement on a basic PACE report chart should be reviewed. For example, the observations of a PACE observer of a particular group for a three week period might be as follows:

	1st Week	2nd Week	3rd Week
Working People	20	22	25
Idle	2	1	2
Out of Area	7	7	3
Loaners	−1	2	0

The indices for the first and second weeks would have already been established on a basic PACE report chart. The figures for the third week are converted into percentages using the PACE formula for manufacturing applications:

$$\frac{[\text{No. Assigned} \pm \text{Loans} - (\text{Idle} + \text{Out of Area})] \times \text{Effort Rate}}{\text{No. Assigned} \pm \text{Loans}} \times 100 = \%\ \text{PACE}$$

Using the figures for the third week, this equation would then read as follows:

$$\frac{30 + 0 - (2 + 3) \times 80}{30 + 0} \times 100 = 67\%\ \text{PACE}$$

On the basic PACE report, therefore, the line representing group effort would be at the 80th percentile, the line representing PACE would be at the 67th percentile, the line representing the number of individuals observed idle would be at the 7th percentile, and the line representing the number of individuals observed out of area would be at the 10th percentile.

PERSONNEL INDEX AND PACE RATING

One of the major comparative values in any cost reduction and productivity evaluation program is the number of individuals required to perform an assigned task. Since PACE Measurement is a measure of change, the personnel dex (in order to be compared with PACE Measurement) must also be a measure of change. This is accomplished by comparing the total number of individuals in a particular department with the total number of individuals in that department the previous week. The resultant ratio is multiplied by 100, so that it becomes a percentage figure and, therefore, is directly comparable to PACE. For example, the formula for determining this equation might read as follows:

$$\frac{\text{This Week}}{\text{Last Week}} = \frac{137}{132} \times 100 = 104.8\%\ \text{Personnel Index}$$

A ratio of this type exceeds 100 percent when individuals are added to a group or department. Conversely, the ratio is less than 100 percent when individuals are removed from a group or department. Using this ratio, large and small groups or departments can be compared on an almost equal basis.

As PACE for a group or department improves, greater benefits are derived from the efforts expended by the working individuals. Therefore, if other factors continue to remain constant, the same amount of work should be accomplished with fewer individuals. As the trend of the PACE line moves upward on the PACE report chart, and if other factors still continue to remain constant, the trend of the personnel index line should be somewhat below 100 percent.

BU GET INDEX AND PACE RATING

All major manufacturing organizations use some form

of budget comparison as a method of performance control. In the sense in which it is used here, budget is usually in terms of hours to be expended. As in other major aircraft organizations, Northrop prepares budget estimates prior to the fact. That is to say, budgets for a specific work function are established in advance of the time that a particular operation is to be performed. At Northrop, the standard procedure is to evaluate (or weight) each work function and apportion the total budget over these weighted parts of the operation. Therefore, by completing portions of the work function, it is possible to earn a certain number of budget hours. Budget realization, then, is a comparison between earned budget hours and actual hours expended, expressed as a percentage. This percentage is established by the following formula:

$$\frac{\text{Earned Hours}}{\text{Actual Hours}} = \frac{3447}{3567} \times 100$$

$$= 97\% \text{ Budget Realization Index}$$

Since budgets are established ahead of the fact, the comparison between budget realization and PACE tends to evaluate the adequacy of the budget. As Pace improves, it can be observed that more effective effort is being obtained from the working individuals. Budget realization should also improve since actual hours expended by the work function continue to decrease, thereby increasing the budget realization index.

Since, as previously noted, budgets are usually established ahead of the fact, it is not at all unusual to find that the trend of the budget realization index will parallel but be somewhat removed from the PACE performance index. The degree to which this separation exists indicates the potential maximum possible budget realization, assuming that systems and methods remain constant.

It is possible to have increases in budget realization without increasing improvements in PACE performance and the reverse of this is also true. Each of these conditions represents a specific influence requiring further analysis. If budget realization increases more rapidly than PACE for example, it may indicate that methods and systems improvements have been effective. If PACE improvement increases faster than budget realization, it may indicate that some external factor (such as parts shortages, for example) is influencing the effectiveness of the group or department.

In most low production rate programs it is especially important to compare only the trends of the budget and PACE lines on the chart rather than the points of these two lines. This fact is particularly important in operations having a small rate of production since it is difficult to weight accurately all of these functions. These smaller operations do not receive the benefit of the smoothing effects that are present in higher rates of production.

In summation, if the budget line is considerably above the PACE line, it is an indication that too much budget is available. Therefore, a budget reduction is indicated. If the budget line runs less than the PACE line, it is an indication that there is insufficient budget to accomplish the task. Of course, in accepting these last two statements as fact, it must be assumed that all other factors are within control.

SCHEDULE INDEX AND PACE RATING

The schedule index, which is a comparison of actual performance (in terms of manufactured units produced) and scheduled performance, is still another equally important control index. This index is the ratio between actual manufactured items produced per unit time to the manufactured items per unit time scheduled to be produced. This ratio is multiplied by 100, resulting in a percentage index. This percentage value is achieved as follows:

$$\frac{\text{Actual}}{\text{Scheduled}} = \frac{4.41}{4.43} = 99.5\% \text{ (of Schedule Produced)}$$

Schedule Index

By comparing this schedule index percentage with PACE performance percentage, it can be noted that (assuming that all other factors remain constant) as the trend of the PACE line improves greater benefit is received from group effort and improvement in the schedule index line should be expected.

The schedule index, as such, shows only that production for a particular week is either ahead or behind schedule. To evaluate the cumulative effect and, therefore, determine a behind schedule condition, it is necessary to evaluate the relative position of the schedule index in comparison with the 100 percent line. Lengthy trends of the schedule index line above the 100 percent line indicate a cumulative ahead of schedule condition.

It is equally as dangerous to be too far ahead of schedule as it is to be too far behind schedule. Therefore (since PACE is improving), it is then necessary to decrease the number of individuals working to control the schedule index so that it remains in the vicinity of the 100th percentile zone on the PACE report chart. This decrease in the number of individuals working will, of course, also be reflected in the personnel index line on the PACE report chart. Similarly, this control of the schedule index will also improve the budget realization index.

QUALITY INDEX AND PACE RATING

The Northrop quality control organization uses statistical sampling methods to determine the quality level for any given group or department. A mean average number of discrepancies per week is calculated by the quality control organization utilizing the history of the preceding ten or twelve weeks. Through additional statistical methods, the Northrop quality control organization also establishes control limits which are plus and

minus three standard deviations from the mean average. Quality levels outside these control limits represent quality deviations which cannot be, under any circumstance, due to chance alone. Therefore, these levels also represent a serious out of control condition as far as quality is concerned.

There are two basic types of deviations which are considered by the quality control organization. One is in terms of percent defective (applicable to sheet metal and machine parts operations), and the other is in terms of numbers of discrepancies per unit (applicable to assembly type operations).

In conjunction with the quality control organization, Northrop's manufacturing methods engineers developed a quality index formula which relates the basic information gathered by the quality control organization to the weekly PACE rating report charts. The formula for this conversion is:

$$\textit{Quality Index} = 100 - \left[\frac{5(P - \overline{P})}{\frac{\sqrt{\overline{P}(1 - \overline{P})}}{\sqrt{N}}}\right]$$

P = % Defective This Week

$\overline{P}$ = Average % Defective

N = Number of Samples This Week

Within the brackets, the numerator represents the deviation from the average percent defective and the denominator represents the standard error of the percentage. The factor 5 in the numerator is used to control the deviation so that a 15 percent deviation from 100 percent represents an out of control condition. The factor 100— is used so that improved quality control is represented by a quality index of more than 100 percent.

Occasionally, the quality index is adjusted. However, the quality index is only adjusted in the direction which would indicate better or tighter quality. When the quality index number is in excess of 100 percent for several weeks, the quality control organization recalculates a new base average.

Using the quality index with the PACE Program, it can be noted that the quality level generally increases as PACE increases but at a somewhat lesser rate. This, of course, indicates that quality does not suffer as PACE strives to utilize more effectively the working efforts of the employees in a given group or department.

SHORTAGE INDEX AND PACE RATING

In any manufacturing program, it is extremely essential to evaluate accurately the effect of potential shortages on the performance of manufacturing functions. At Northrop, there are three major classifications of shortages: cushion shortages, which are defined as a supply of ten days or less in the bins; top priority shortages, which are classified as those parts for which there is no supply in the bins; and shutdown shortages, which are established as those parts which, when short, prevent further manufacturing activity in the particular area which they affect.

The shortage index developed by Northrop's manufacturing methods engineers is a ratio of the number of top priority shortages in a department compared to the total number of different parts which are supposed to be in the department. Since this ratio is small, the ratio is multiplied by a shortage factor as follows:

$$\frac{\text{Top Priority Shortage}}{\text{Total Number of Parts}} \times \text{Shortage Factor} = \frac{378}{2056} \times 250$$

$$= 46\% \text{ Shortage Index Number}$$

The shortage factor is developed independently for each department. Past history has indicated that a maximum of one percent in top priority shortages can be tolerated in some departments, and as little as one-tenth of one percent in other departments.

In general, when working individuals find that there are no parts left in the bins, they tend to stretch out the current work to make certain that it will last the rest of the working day. PACE Measurement, of course, observes the effect of this stretchout. Shortages are considered to be under control when the index number is less than 5 percent on the PACE rating report chart.

PACE PROGRAM COMPARATIVE ANALYSIS

Having briefly discussed how each of the current performance indices is developed, we should now consider the interrelationship of all of these indices and PACE Measurement. When all of the measures of performance, including PACE, are within the controlled area (PACE, personnel, budget, schedule, and quality around 100 percent; and shortages, out of area, and idle time below 5 percent) it can be noted that a department is in control. Any time any of the measures of performance deviate from this controlled condition, the fact that a problem exists becomes instantly apparent. By considering which index line appears to be out of control, the area in which to begin investigation can immediately be established. By reviewing all of these factors, prompt preventive action can be applied rather than waiting until all parties concerned recognize a serious out of control condition and then have to apply more costly corrective action.

At present, the PACE report chart contains eight lines, each of which is a measure of performance. Considering the variety of trends and directions of these lines, there are over 700 possible combinations in which these lines may progress. Each combination is indicative of a different set of conditions—some of which are desirable, but some of which are undesirable. Each of the undesirable conditions indicates a problem area. The particular combination of trends indicates a specific problem area rather than a general type of problem and permits analysis of this problem area so that the aforementioned preventive action can be applied promptly.

At this point, assume a set of conditions and then analyze the department in much the same manner as a

manager does. Assume, for example, that PACE is improving and the personnel index shows a level trend at 100 percent; that the budget realization is improving and is somewhat parallel to PACE; that the schedule index shows improvement but is in excess of 100 percent; that the quality index trend is level at 100 percent; and that the shortage index is improving but is still above 5 percent. Under these conditions, the department head will undoubtedly exert lateral pressure on the organization which is to supply parts to his department in an attempt to further improve the shortage index. He will also exert pressure on his lieutenants to increase the efforts of the working individuals and further reduce their idleness and out of area time. As these pressures become effective, an increase in PACE will be observed. Since the efforts expended by the working individuals are being more effectively utilized, the budget realization will continue to increase. Since the schedule index shows that this department is already producing at a rate which will put it ahead of schedule, the number of people available to accomplish the work must be reduced so that the schedule index line can be brought under control. In other words, the schedule index line should level off right around 100 percent. This, of course, means that the department is accomplishing more work with less people; therefore, budget realization will further improve. It can also be noted that over the long term, the quality index will show some improvement. As budget realization improves, it is necessary then to readjust the budget to remain more in line with PACE improvement. This adjustment represents a real savings to the department and, therefore, to the company. This adjustment further represents an improvement in managerial technique, so that additional benefits may be realized on this product and additional business through lower cost may be realized on future products.

As PACE continues to improve, assuming now that the schedule index remains relatively constant around 100 percent, further reductions in personnel are indicated, with a resultant further improvement in budget realization. To keep trends in this direction, the department head must continually apply pressure laterally to insure that he has the proper tools, the right number of parts, and the proper working conditions under which to operate. The unique point about this program is that by reviewing his weekly PACE rating report chart, the department head knows the direction in which to apply his efforts to receive the greatest benefit for his department.

The department head and higher levels of management now have all the indices of performance graphically correlated in one frame of reference. Management can then tell at a glance whether the department is under control and deserves commendation, or whether the department is out of control and requires remedial action. The PACE rating report chart indicates the specific out of control factor necessitating immediate managerial attention.

DISSEMINATING PACE TRENDS AND PERFORMANCE INDICES TO MANAGEMENT

Having discussed the value of the PACE Program;

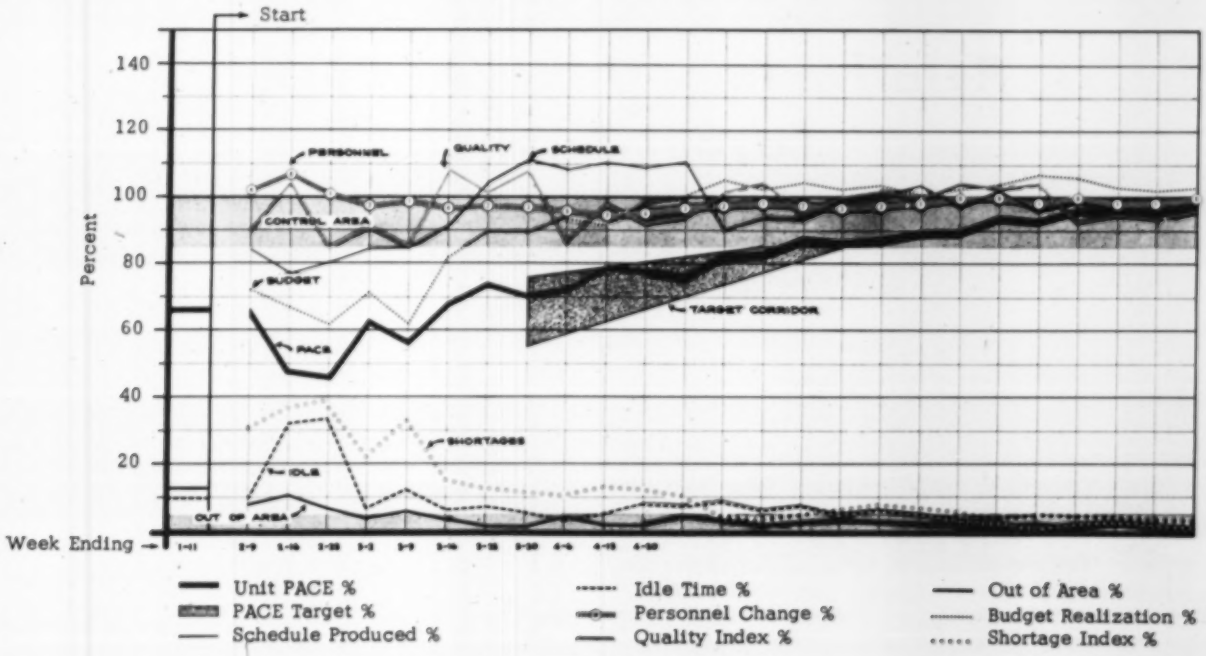

FIG. 4. Weekly PACE Program Report Chart.

that is, PACE Measurement plus the comparison of other indices of performance, the method of communicating this information to management should be considered.

WEEKLY PACE MEASUREMENT REPORT

Each week, the daily PACE Measurement observations are summarized and the summary of this information is plotted on $8\frac{1}{2} \times 11$ inch reproducible PACE report charts as illustrated in Figure 2. The PACE reports are duplicated and distributed so that each department head receives a copy of the chart reflecting PACE activity in his particular department.

PACE PROGRAM REPORT CHARTS

20×30 inch color charts for each department similar to the chart illustrated in Figure 4, are continually revised and maintained. These charts are available to all levels of supervision and management for study and discussion purposes.

MANAGEMENT CONFERENCES

Each week, regularly scheduled meetings are held at the managerial level to discuss the interpretation of the trends of PACE and the performance indices. At this time, these trends are evaluated and the application of preventive measures necessary to correct the beginning of any adverse trend is determined. Numerous unscheduled meetings are also held with first-line supervision to discuss methods of improving problem areas which have been indicated by the PACE reports.

OFFICE AND TECHNICAL APPLICATIONS OF PACE

The application of PACE Measurement and the PACE Program to office and technical departments is relatively simple and has been accomplished through minor modifications in the PACE Measurement formula and PACE observational methods and techniques.

CONCLUSION

The Northrop experience has proven conclusively that the installation of the PACE Program resulted in sustained trends of greater group output and effectiveness. These improvement trends were immediately reflected in the fields of cost reduction and schedule position without any sacrifice in the quality level.

Line supervision and their management found in the PACE Program a valuable tool through which required remedial action could be immediately applied. They found, too, that the controls established by PACE were at once sensitive and effective. PACE provided both essential detail control for specific areas and simultaneously gave a panoramic picture of all factors necessary to comprehensive control.

The incorporation of the PACE Program in any operation is relatively economical, yet its application by any organization can reflect substantial improvement in the competitive position of that firm. The primary requirements for establishing this PACE Program as a new tool to be used by all levels of management and operating supervision are: the enthusiastic support of management, and the availability of highly skilled professional analysts.

Relative Importance Factors in Layout Analysis

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THE USE of travel charting and related techniques by Industrial Engineers continues to increase as more and more individuals become familiar with the advantages of such an approach to layout problems. However, since the earliest presentations of travel charting by Cameron (1) and Smith (4), the question of realism has plagued the user. The requirement of too many simplifying assumptions has been a constant source of difficulty. Llewellyn (2), in developing a charting technique using more realistic distance criteria, helped the situation to a considerable degree. There remained, however, some additional barriers to be cleared before the technique could become a really practical method of solving plant layout problems. Wimmert (5) and others have dealt with location problems on a mathematical basis, but the methods have been rather complex and are not the same sort of technique. This article will deal with one of the vital omissions from previous methods—the inclusion of relative importance factors in layout analysis together with a layout moment ratio which permits comparison and measurement of the overall value of a layout.

Certainly a matter of basic concern in determining the

physical location of work centers is the question of considering additional factors affecting product movement and its relationship to the system as a whole. The usual factors of volume of product and distance are rarely adequate for satisfactory layout design. Other things are too important to overlook. Examples of such other factors might be the priority of one product over others, hazardous moves which should be as short as possible, unusually valuable or fragile materials, and the undesirability of congestion, cross-flow, or counterflow.

The method of solution presented provides a way of including information concerning the *relative importance* of various material moves. The authors feel that this relative importance should be allowed to affect the layout and that it must therefore occupy a strong position in any practical method of analysis.

ESTABLISH PRIMARY DATA

The data required for solution of layout problems should be readily procurable for a given production system. These data should include the production rate of each item, the production sequence of each item, the approximate space requirements for each work center, the space available for placement of the work centers, and the number of units of product moved per load.

Both the production rate and the units of product per load should be specified in the same terms. While some companies might find it better to use some other convenient parameter, the example problem explained here uses units per time period.

The production sequence is stated by number: e.g., a product which starts at production center 1 and then progresses to centers 4, 6, and 8, in that order, would be specified simply as 1-4-6-8.

Space requirements and space available are ordinarily given as square footages. If special shapes for certain areas are required, that must be considered in making relayouts. In the same way, if safety or some special production or shipping facilities dictate that a certain center must occupy a specific position, that, too, must be taken into acount when designing the layout revisions. All of these factors will, of course, be familiar to the experienced layout man accustomed to dealing with them.

The data to be used in the example problem are presented in Table 1, Table 2, and Figure 1.

ESTABLISH AND WEIGHT IMPORTANCE FACTORS

An *Importance Factor* will be defined as any factor other than volume of product or distance to be moved

TABLE 1
Production Data

Product	Sequence	Units/Unit Time	Units/Load	Loads/Unit Time
z	123678	1000	25	40
y	126548	2000	20	100
z	13458	500	20	25

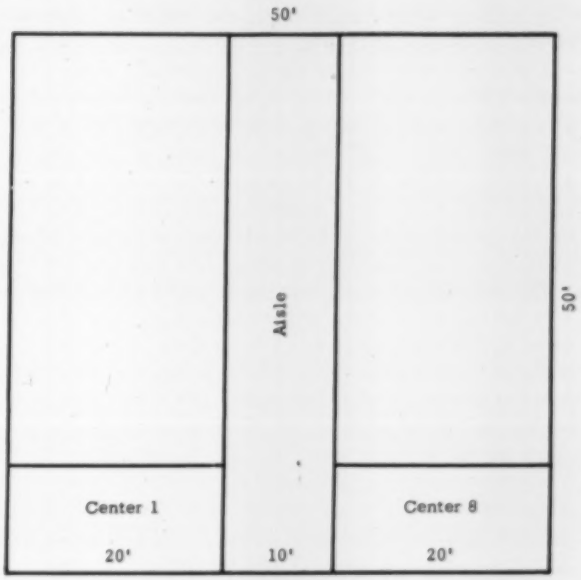

FIG. 1. Total Area Available for Example.

that is to be considered in determining a good plant layout from a materials handling point of view. It is important that these factors be included in analyzing a layout, although with older approaches to the problem, they frequently have been ignored.

The actual selection of things to be considered will depend upon the individual plant and its personnel. What is significant to one concern may be of no significance whatever to another. The exact list of factors and the rank or weight assigned to them must be determined by the Industrial Engineer in cooperation with other staff and line personnel.

TABLE 2
Production Center Data

Number	Center	Area (Square Feet)
1	Receiving	200 (Location fixed)
2	Bandsaw	300
3	Lathes	100
4	Grinders	400
5	Milling Machines	200
6	Drill Presses	200
7	Polishers	400
8	Packaging	200 (Location fixed)

Importance factors will be used to determine adjustments which will be applied to either the distances to be moved or to the volume of material to be moved. It will be noted that some adjustments will remain the same for all layouts, while a second group will apply to different moves as the layout is changed. The constant adjustments will be applied to the moves in establishing *adjusted load values*, while the variable adjustments will be applied to the distances between the various produc-

tion centers when establishing the *adjusted distance values* for a specific layout.

A material move which has no importance factors associated with it will have an adjustment factor multiplier of 1.0. As a rule, it will be desired to have moves with the most importance attached to them be the shorter moves, if possible. In order to make the moves with the highest load values tend to become the shorter moves as the layout is improved, the adjustment factor multipliers associated with them will be set greater than 1.0.

The determination of how much adjustment is necessary for the various importance factors must be a judgment of the persons doing the analysis, based on experience, consultation with plant personnel, and data peculiar to the individual situation. The weighting should be within the capabilities of the engineers assigned to plant layout work.

Referring to our hypothetical example, let us say that it has been found that product y is our most stable product in terms of sales. It is likely that product y will be produced for a long period of time, perhaps after products x and z have been discontinued. Therefore, we will attach more importance to the moves of y than to those of x and z. In other words, we want to design our layout primarily around product y. It is decided that a move of product y should be considered 1.4 times as important as a move of product x or z. Therefore, an adjustment of 0.4 will be added to the base of 1.0 to determine the multiplier for the portion of the moves associated with product y. These adjustments are listed in Table 3.

TABLE 3

Product Priority Adjustments

Move	Adjustment	Multiplier
Product y, 1 to 2	0.4	1.4
Product y, 2 to 6	0.4	1.4
Product y, 6 to 5	0.4	1.4
Product y, 5 to 4	0.4	1.4
Product y, 4 to 8	0.4	1.4

Product x has a radioactive capsule placed in it at product center 6. It is important that moves of product x through the plant be held to a minimum distance after product x leaves production center 6. It is felt, therefore, that a high adjustment of 1.0 should be added to the base of 1.0 to make up the multiplier for those moves. See Table 4.

In the example, normal flow has been defined as clockwise, both along aisles and across them. For this plant, it has been decided that counterflow is undesirable, and that counterclockwise moves should be kept as short as possible. This is not considered as important as the other factors, so an adjustment of 0.2 will be applied for the appropriate moves for each layout as it is developed; the multiplier will thus be 1.2.

TABLE 4

Hazardous Move Adjustments

Move	Adjustment	Multiplier
Product x, 6 to 7	1.0	2.0
Product x, 7 to 8	1.0	2.0

ESTABLISH ADJUSTED LOAD AND DISTANCE VALUES

An *Adjusted Load Value* is defined as the product of the volume of the material moved and the constant adjustment multipliers. This value consequently remains the same for all layouts. In the sample problem, the move 1-2 will have a load value of 180; this is the result of multiplying the 100 loads contributed by product y by 1.4 and the 40 loads contributed by product x by 1.0, then summing the products. The adjustment multipliers of Table 3 and Table 4 are the constants used. Table 5 shows adjusted load value calculations for the entire example.

Different *Adjusted Distance Values* must be established for each layout which is considered, since the values are dependent upon the layout. A trial layout for the example problem is presented in Figure 2, and the determination of its adjusted distance values is shown in Table 6. The distances shown are measured from the midpoint of one work center out to the middle of the aisle, along the aisle, and in to the midpoint of the next work center in the sequence. Under the previously stated assumptions, the only adjustment made was to multiply by 1.2 for all moves opposite to normal flow.

TABLE 5

Determination of Adjusted Load Values

Move	Product Loads/Unit Time			Loads	Multipliers	Adjusted Load Values
	x	y	z			
1 to 2	40			40	1.0	
		100	0	100	1.4	180
1 to 3	0	0	25	25	1.0	25
2 to 3	40	0	0	40	1.0	40
2 to 6	0	100	0	100	1.4	140
3 to 4	0	0	25	25	1.0	25
3 to 6	40	0	0	40	1.0	40
4 to 5	0	0	25	25	1.0	25
4 to 8	0	100	0	100	1.4	140
5 to 4	0	100	0	100	1.4	140
5 to 8	0	0	25	25	1.0	25
6 to 5	0	100	0	100	1.4	140
6 to 7	40	0	0	40	2.0	80
7 to 8	40	0	0	40	2.0	80

ANALYSIS, IMPROVEMENT, AND EVALUATION

In searching for places where improvements in the layout may be made, we will be concerned with the combination of adjusted loads and adjusted distances. These may be studied individually or in the form of moments, depending upon the information being sought.

For purposes of identifying move paths which offer maximum opportunity for improvement, there must be some basis for comparing the situations for the various moves with one another. It is useful to multiply the adjusted loads by the adjusted distances; the moment thus obtained provides an index of the effectiveness of the move in question. In general, the moves having the highest moment will be those which merit most consideration in planning changes in layout. Under certain circumstances, of course, this may not hold, but most applications include cost considerations involving such moments.

For the sake of convenience, many will find it desirable to set up a tabular form of recording the adjusted distances and moments. An arrangement such as that shown in Table 7 can be used directly in deciding which moves should receive the greatest attention in planning changes. Table 7 shows values for the layouts of Figure 2 and Figure 3. As additional layouts are proposed, they may be compared directly with the previous one by simply adding another column to the table.

TABLE 6

Determination of Adjusted Distance Values For Layout of Figure 2

Move	Total Distances			Multiplier	Adjusted Distance Values
	To Aisle	Aisle	From Aisle		
1 to 2	(15.0	+12.5	+15.0)	1.0	42.5
1 to 3	(15.0	+22.5	+15.0)	1.0	52.5
2 to 3	(15.0	+10.0	+15.0)	1.0	40.0
2 to 6	(15.0	+17.5	+15.0)	1.0	47.5
3 to 4	(15.0	+12.5	+15.0)	1.0	42.5
3 to 6	(15.0	+ 7.5	+15.0)	1.0	37.5
4 to 5	(15.0	+ 5.0	+15.0)	1.0	35.0
4 to 8	(15.0	+35.0	+15.0)	1.0	65.0
5 to 4	(15.0	+ 5.0	+15.0)	1.2	42.0
5 to 8	(15.0	+40.0	+15.0)	1.0	70.0
6 to 5	(15.0	+10.0	+15.0)	1.2	48.0
6 to 7	(15.0	+15.0	+15.0)	1.0	45.0
7 to 8	(15.0	+15.0	+15.0)	1.0	45.0

LAYOUT MOMENT RATIO

While the moments themselves provide the key to path improvement, it is often desired to measure the overall value of a layout in some manner. Perhaps as suitable a way as any is to take the ratio of the total moment for the original or existing layout to the total moment for the proposed layout. This "layout moment ratio" will serve as a way to compare the different proposed layouts if the original layout's moment is always used as the numerator. The larger the moment ratio becomes, the more desirable the layout will be, for most applications.

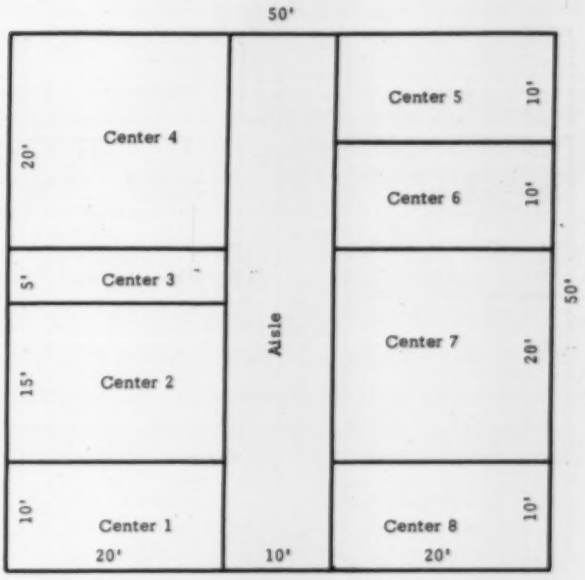

FIG. 2. Layout Number One.

Where distances alone are of interest, it would be possible to work with only adjusted distance values, since the adjusted load values remain constant for an individual move. However, because the relative importance factors and the product volume which appear in the load values must also be considered in making location decisions, it is almost always preferable to calculate the moments and work directly with them. Further, for evaluating the layout moment ratios, it will always be required to find the total moments formed by summing up the individual path moments. This is necessary because the sum of a group of moments is not the same figure as the moment formed by multiplying together the sums of the various components.

TABLE 7

Layout Analysis Work Sheet

Move	Layout One			Layout Two	
	Adj. Loads	Adj. Dist.	Moment	Adj. Dist.	Moment
1 to 2	180	42.5	7650	42.5	7650
1 to 3	25	52.5	1313	52.5	1313
2 to 3	40	40.0	1600	40.0	1600
2 to 6	140	47.5	6650	47.5	6650
3 to 4	25	42.5	1063	37.5	938
3 to 6	40	37.5	1500	37.5	1500
4 to 5	25	35.0	875	54.0	1350
4 to 8	140	65.0	9100	45.0	6300
5 to 4	140	42.0	5880	45.0	6300
5 to 8	25	70.0	1750	60.0	1500
6 to 5	140	48.0	6720	30.0	4200
6 to 7	80	45.0	3600	40.0	3200
7 to 8	80	45.0	3600	70.0	5600
Total Moments			51301		48101
Layout Moment Ratio			$\frac{51301}{51301} = 1.00$		$\frac{51301}{48101} = 1.07$

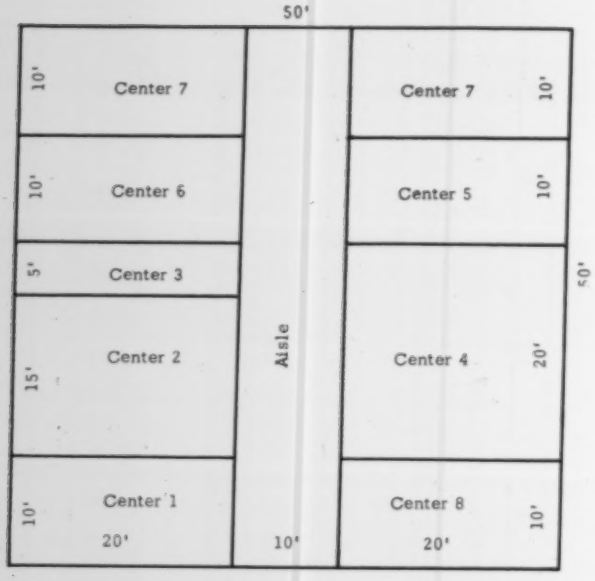

FIG. 3. Layout Number Two.

In the example, the information for Layout One was first collected and tabulated. Changes in the layout were then made, utilizing the usual planning methods, but emphasizing the moves having high moment values. Layout Two resulted; this is not claimed as the ultimate possibility, but represents an improvement, as shown by its "layout moment ratio" of 1.07. Perhaps the most striking improvement was effected in move 4-8, where the moment was reduced from 9100 to 6300.

APPLICATION

In "real life," the various considerations involved in using the technique described will not, of course, be nearly so simple and straightforward as the small example given. Many problems of definition and procedure will be encountered: for instance, aisles and their interrelationships, counterflow versus regular flow, department shapes, and locating the "center" or "average" points of the work centers and departments.

It will be found that in some cases it is useful to use the actual average distances travelled, instead of considering all flow to begin and end at central points. Also, there will be questions concerning flow inside a department, or flow which enters and leaves a work center at different points. The position of conveyors in the scheme of things can cause complications. Other factors, peculiar to each individual situation, will be sure to arise; these are too numerous to mention and impossible to predict completely, since they will be different for every case.

The important thing is to recognize this particular method of attack for what it is: simply a logical way of organizing necessary information in a usable form. While it can be of real value in solving layout problems, it will not do any more than serve as a tool. The actual construction of new layouts must still be done by means of the usual planning techniques, and in any case the existing conditions and common sense must be used in any application. So long as the designer is consistent in the way he calculates and utilizes the information required for the analysis, any variations or special "ground rules" required for specific cases need not affect the utility of the method.

SUMMARY

By the use of the tools described, a more realistic solution to plant layout problems may be obtained. The most important distinctions between the method proposed and previous approaches are:

1. The recognition of the factor of relative importance of moves.
2. The elimination of need for constructing the various types of travel charts.

In outline form, the method is:

1. Establish primary data.
2. Establish and weight importance factors.
3. Establish adjusted load and distance values.
4. Analyze, improve, and evaluate layouts.
5. Repeat steps 1 through 5 as required.

REFERENCES

(1) CAMERON, D. C., "Travel Charts—A Tool for Analyzing Material Movement Problems," *Modern Materials Handling*, Vol. 7, January, 1952, p. 37.

(2) LLEWELLYN, ROBERT W., "Travel Charting with Realistic Criteria," *Journal of Industrial Engineering*, Vol. 6, No. 3, May-June, 1958, p. 217.

(3) LUNDY, JAMES L., "A Reply to Wayland P. Smith's Article," *Journal of Industrial Engineering*, Vol. 6, No. 3, May-June, 1955, p. 13.

(4) SMITH, W. P., "Travel Charting," *Journal of Industrial Engineering*, Vol. 6, No. 1, January, 1955, p. 13.

(5) WIMMERT, R. J., "A Mathematical Method of Equipment Location," *Journal of Industrial Engineering*, Vol. 9, No. 6, November-December, 1958, p. 498.

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New Concepts of the Learning Curve

by **E. B. COCHRAN**[1]

Budget Manager, Rohr Aircraft Corporation

THE Learning Curve (L/C)[2] is a powerful tool of cost forecasting and control. It gets this power because it features areas and possibilities of change. It is a *dynamic*, not a *static* concept, and in this respect is similar to another key tool of cost control—variable costing and budgeting. For non-aircraft industries, the learning curve opens up an entirely new dimension of cost analysis to add to those already defined by specialization of function, time study, mass production tooling, etc.

However, its present uses are still sharply limited in relation to its potential.

1. Outside of aircraft and missiles, it is still hardly even recognized.

2. The aircraft-missile industry seems to have reached a plateau in its use and a dearth of new ideas. New work is limited mainly to simple repetition of the ideas expressed by T. P. Wright in 1936, and rather unimaginative efforts to develop industry-wide codification of data.

3. One almost suspects that the L/C's popularity in aircraft derives mainly from the simplicity of its use—being developed merely with graph paper, a ruler and pencil.

The time seems appropriate for more careful examination of the basic cost function, and for discarding the usual broad treatment for study of specific manufacturing conditions and parameters which relate them to cost trends. This article is an effort to do just that. After reviewing basic concepts and their more immediate implications, it probes various applications and attempts to develop new concepts and locate concrete techniques of Industrial Engineering with which sound liaison may be established.

Several revised applications and new concepts of learning curve analysis are developed as a result. These techniques have already indicated considerable promise in actual application. If tested and used on a wider scale, the art of cost prediction and control will gain a tool of great precision and reliability for use in many industries.

[1] The author would like to express his indebtedness to several executives of Rohr Aircraft Corporation whose thoughts and analysis of learning curve experience contributed significantly to this paper: A. K. Openchowski, Manager of Industrial Engineering and Scheduling; W. G. Koehler, Manager of Manufacturing Methods; and H. C. Emerson, General Production Superintendent.

[2] This is sometimes more accurately called the "Manufacturing Progress Function."

BASIC COST CURVES

Let us begin with a typical cost curve for the early stages of production up to 5000 units. Most data, illustrated by Figure 1, show a very rapid drop as we go from unit 1 to unit 1000, and continue at a more gradual pace of reduction from there on to unit 5000.

The chart also shows an expanded view of the cost from unit 0 to unit 1000. Note that from units 0 to 50 the costs are so high as to go off the chart. Obviously some other technique must be used if we are to easily study cost performance in this volume range.

The tremendous importance of early unit costs to a program of 1000 to 5000 units is indicated by Figure 2, which plots cumulative costs through unit 1000.

From this we see that the first 500 units contribute over 70% of the costs for a program of 1000. Early control is *crucial*, and warrants refined techniques to forecast and control the cost of units early in a program.

To place this type of data in manageable form, it is often replotted on a log-log chart. This permits comparison of wide ranges of data since it plots *logarithms* of cost and unit data rather than the values themselves. And since a logarithm is merely an *exponent*, it

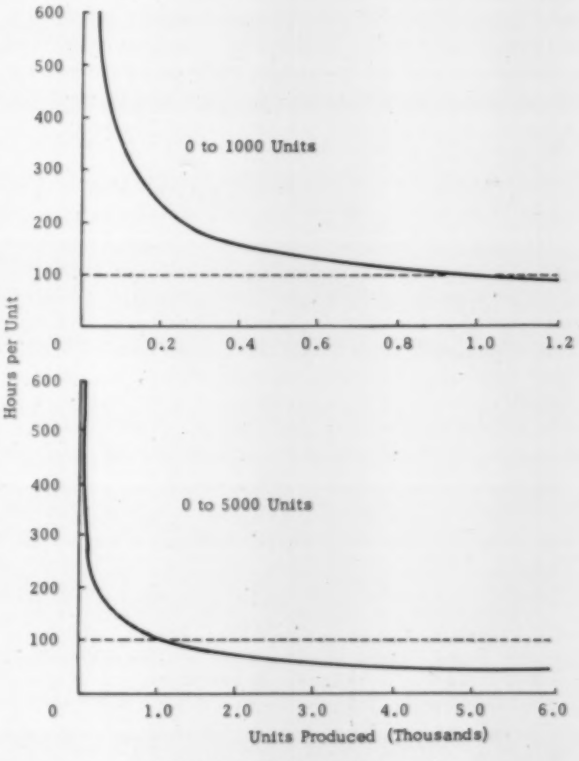


FIG. 1. Basic Cost Curves.

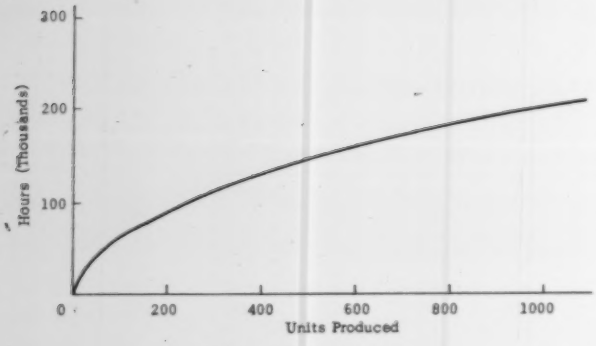


FIG. 2. Cumulative Costs.

rises slowly with a large increase in a value.

Interestingly enough, these data plot as a straight line, or approximately so. (See Figure 3.) This discovery by T. P. Wright was an important one since it offers a very simple means of studying costs. As a result, expressing the cost of unit n as $C\ (n)$:

$$\text{Log } C(n) = \text{Log } C(1) - b \text{ Log } n.$$

where b is some constant and $C(1)$ = cost at Unit 1.

$$\therefore \text{ Log } C(n) = \text{Log } C(1) + \text{Log } n^{-b}$$

$$C(n) = C(1) \cdot n^{-b} \qquad \text{Eq. 1.}$$

The equation turns out to represent a wide range of cost relationships.[3] By suitable choice of the exponent b one can develop curves in which at one extreme the cost of the second and tenth units are 93% and 80% respectively of that for unit one, or at the other, the costs of units two and ten are 25% and 1% of unit one.

In the formula $C\ (n) = C\ (1)\ n^{-b}$,

Value	*Ratio to First Unit Cost*	
% b	*Unit 2*	*Unit 10*
0.10	93%	80%
0.50	71	31
1.00	50	10
1.50	36	3
2.00	25	1

Therefore we have the makings of a flexible tool suitable to many industries.

Another form of the basic equation is obtained by relating the values for two unit numbers:

$$\frac{C(m)}{C(n)} = \frac{C(1) \cdot m^{-b}}{C(1) \cdot n^{-b}} = \frac{m^{-b}}{n^{-b}} = \left(\frac{m}{n}\right)^{-b} \qquad \text{Eq. 2.}$$

[3] In some discussions, the straight line log/log function is taken as the *cumulative average* unit cost. This practice is not followed here for several reasons, chiefly because this practice tends to smother the actual performance. In any event, such a mathematical model as this can prove its validity only on the basis of successful fitting to actual or projected operating conditions. Such fitting of the unit cost function will be discussed at length in this article.

This is then easily transformed into the familiar learning curve terminology by considering those points $m = 2n$, so that:

$$\frac{C(2n)}{C(n)} = 2^{-b} \qquad \text{Eq. 3.}$$

and $$C(2n) = C(n) \cdot 2^{-b} \qquad \text{Eq. 3a.}$$

This might be termed the "normal form" of the equation. It will also plot as a straight line on Log/Log paper, and may be expressed in the form:

$$\text{Log } C(2n) = \text{Log } C(n) - b \text{ Log } 2 \qquad \text{Eq. 4.}$$

The ratio of $C\ (2n)$ to $C\ (n)$, or 2^{-b}, is commonly used to designate the "slope" of the curve, even though it might be more accurately designated by the exponent b alone. When $2^{-b} = .80$, we are said to have an "80% curve." A fairly linear relationship exists between values of b and 2^{-b} for normal ranges of b.

The learning curve has been extensively used in aircraft production and related industries where relatively low quantities of production occur and opportunities exist for rapid cost reduction early in the life of new products. Various "rates of learning" have achieved some recognition as appropriate to various types of manufacture, such as assembly (70-80%), machining (90-95%), welding (80-90%) and so on. By appropriate choice of learning curves for the elements of production cost, a powerful tool of cost prediction has been developed, for use on a company's own production activities as well as on its outside suppliers.

But despite its apparent potency, the learning curve has not begun to yield the results of which it is capable.

1. It is applied on a far too general basis—generally to entire major departments encompassing several types and rates of learning, and its accuracy may be severely damaged by this practice.

2. The *shape* of the curve in the one to 100 range can be of critical importance. There is a wide range of error in straight-line curves.

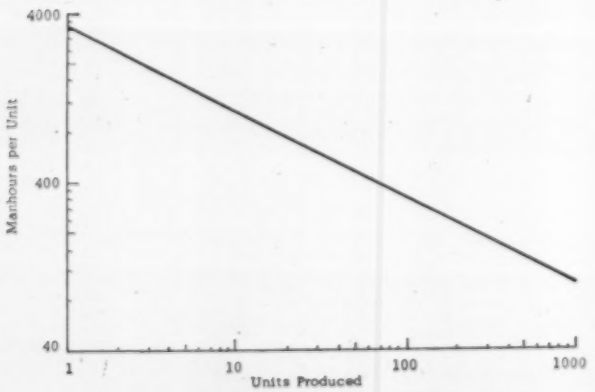


FIG. 3. Log/Log Chart of Costs.

3. There seems to have been insufficient attention to *why* learning occurs at this or that rate, the degree to which it speeds up or slows down on a given job, and the level at which a job's overall cost should occur.

Without closer attention to these things the learning curve must remain merely another interesting check on overall cost trend projections. As such its apparent precision can be positively misleading when used for shop budgets or procurement targets.

THE UNIT OF LEARNING

In order to utilize cost functions for forecasting and control purposes, it is convenient to choose a *reference point* on the curve in terms of which other costs are expressed. Two practices are used in learning curve analysis:

1. Reference Point as C (1)
2. Reference Point as C (x)

where x = a point of solid company or industry experience; for example, x = unit 1000. For an R and D company, x might be taken as unit 50 or an average for the first 50 units.

There is considerable argument as to which approach is the "better." Actually they can be equivalent, but the second one seems to be more easily interpreted and utilized by production companies. Their experience is better expressed as a unit cost attained some ways down the line after special problems are shaken down and cost data are sounder, so that estimating techniques become more reliable. We will therefore take the "normal" or "standard" cost of unit 1000 as a reference point for the curve during this discussion.

Now, using the second approach, is unit x = 1000 (for example) actually the 1000th unit produced?

Not necessarily. The cost of unit 1000 is generally found as a combination of cost elements for individual operations as they would appear after 1000 *repetitions*. But the combination itself will not necessarily make a 1000th item overall. Many components and operations will be present in multiple quantities, and some may not occur on every unit. Of course it is possible to have a case where estimates are based on actual experience measured at the 1000th item produced. This may yield a correct estimate for unit 1000 when applied to closely similar items, but application to new items will distort its accuracy in rapidly increasing degree.

The concept of the 1000th (or xth) unit must be properly interpreted for each concrete case. We must identify exactly what constitutes the unit of learning so that the "1000th unit cost" may be correctly located on the end-product sequence. This unit of learning may be the end-product itself. But it may equally well be a component having multiple or only occasional use on the end-product.

COST EFFECT OF CHANGES IN LEARNING RATES

Now we turn to the first real refinement of our basic

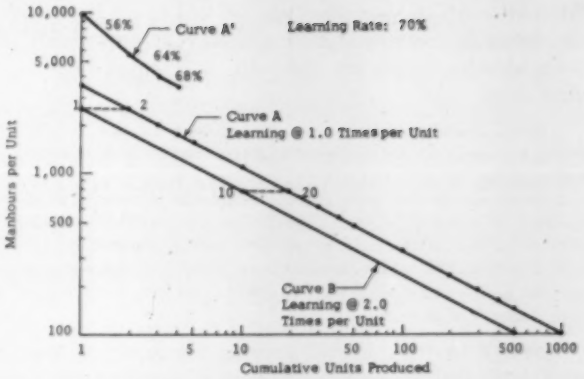


FIG. 4. Cost Effect of Changes in Learning Rates.

L/C concept. That is, the idea that learning may not occur exactly *once* per unit, but either faster or slower. Figure 4 shows what happens when a cost curve is drawn on two assumptions:

1. Learning *once* per unit (our regular curve).
2. Learning *twice* per unit (obtained by moving out to unit 4 for the cost of unit 2, unit 6 for unit 3, etc.).

It will be seen that the second curve reaches the cost of the first's unit 1000 by the time it gets to unit 500. In general the costs along the second curve drop a constant proportion (30% for a 70% curve) and the curve drops a constant amount to a parallel position, since this is a logarithmic scale. This result follows from our basic formula $C\ (2n) = C\ (n) \cdot .70$.

An interesting conclusion is reached. *Any change in learning rate is equivalent to a change in the unit at which standard cost is reached.* And this in turn generates a major shift in the entire level of cost. Obviously the determination of learning rate is of major significance in forecasting and controlling costs!

For example, consider an engine pod for a four-engined aircraft. In planning airframe costs, it is customary to consider the aircraft as a unit of learning. But separate study of engine pod costs (as is done when these are made by a subcontractor) indicates the possibility that each pod may be a unit of learning. This conclusion may only be reached, of course, after careful analysis of tooling, methods, work flow and manpower assignments demonstrates sufficient similarity in processing of each pod and its components. In the course of this, we may find that specific areas may be able to learn only once per ship-set of four pods, or perhaps even more than once per pod (four times per ship-set) as when several closely similar components of a pod are produced in a workcenter by repetitive methods.

FACTORS IN LEARNING

If the learning curve is to become a real tool, we must develop this *rate* aspect of learning. What affects it?

What elements of shop practices are tied to it? How can the causes be measured? How can they be predicted?

To identify accurately the unit of learning requires three steps:

1. Break down the task into specific major workcenters—fabrication vs. assembly, for example, and the individual workcenters within those.
2. Study the flow of work in each workcenter to determine the rapidity of learning in each and the unit at which the workcenter's portion of the total 1000th item cost is attained.
3. Combine the detailed results into composite judgments on the end product unit at which the 1000th item cost is attained in each major type of cost.

In order to pinpoint the learning factor, let us start with perhaps the most basic part of it—*worker learning.* In analyzing that, we shall consider a typical case of aircraft-type assembly operations in one cost center. In applying this approach to electronic or machining activities, for example, some differences in approach would be necessary.

That portion of cost reduction due primarily to improvement in performance by the direct worker has been estimated by one study at roughly 40% of the cost above that at unit 1000. This improvement is accomplished primarily through repetitive performance of a task in the presence of consistent supervision and reasonably stable methods and tooling. The potential for such improvement may be determined through analysis of a flow diagram for each cost center which involves such factors as:

1. Number of stations.
2. Jigs per station.
3. Units in process.
4. Number of crews and shifts.
5. Traveling of crews between jigs (repetition of assignment).

One approach to evaluating these matters is outlined:

	Station			Average or Total
	I	II	III	
1. End Units in Process	2	3	1	6
2. Number of Jigs	8	12	1	21
3. Jigs/Unit (2÷1)	4	4	1	3.5
4. Shifts Worked	2	1	1	—
5. Men per Station	12	10	8	30
6. Repetition and Memory Factor[4]	0.8	0.7	1.0	0.82
Learning per Unit (3÷4)×6 or (2×6)÷(1×4)	1.6	2.8	1.0	1.84

It may be seen that overall worker learning comes out at 1.84 times per unit, so that "standard cost" should be hit at unit 543. The *unit of output is not necessarily the unit of learning!* This may be obvious when we consider that *one* transport aircraft may have *four* power plants and *two* wing sections. But it is also true of *each* of those components and of their sub-assemblies in turn. This technique and others like it have actually been tested on a large number of cost centers and found to be most helpful in setting cost targets and in stimulating attention by methods personnel to reorganization of work flow and crew assignments. Often the tendency is to allow one crew per jib, but there are generally ways to redefine assignments and permit crews to travel from jig to jig within the station. In this way a crew can perform a group of operations on more units and increase the learning per end-product.

It is obvious that circumstances peculiar to different companies and manufacturing processes could have considerable effect on rates of learning. Further investigation by many companies should produce interesting and useful ideas.

MEASURING OTHER AREAS OF LEARNING

But of course, worker learning is only one controlling element, although a major one. Other factors such as tooling, supervision, parts design and shortages will affect the rate of cost reduction.

To blend all these into one composite judgment on one rate of learning requires certain steps:

1. Identify the relative importance of each factor to the learning rate.
2. Establish the influence of the particular factor upon the unit at which standard cost will be achieved (in effect the rate of learning).
3. Work out a statistical combination of each factor to permit computing the overall rate of learning.

At present establishing the relative importance and improvement pattern of each area must be heavily flavored with judgment, and is complicated by the fact that these will differ between cost centers. But with persistence experienced Industrial Engineers should be able to arrive at workable results.

Certain guide lines should be considered:

1. Tooling improvement seems to occur more with time early in a program than with actual output, with some tendency for faster improvement for several jigs of similar design than for only one. There is some evidence that an early period of slow improvement is followed by a time of more rapid improvement, and then by a slow steady rate of improvement as output increases. Generally it would seem that tooling reaches "normal" efficiency somewhat earlier than direct labor does, with different cost patterns for early units reflecting the degree of pre-planning, tool proofing and experience with similar products.
2. Supervisory contribution to cost reduction would seem to advance with unit output, since changes in cost per unit are the basic guidance for supervision on its effectiveness. However a complex supervisory structure or extensive technical requirements of the supervision may slow the learning in some instances.
3. The effect on learning of parts (or material) availability, and quality improvements, may vary with the basic complexity of the parts themselves. The exact degree must be judged for each workcenter in the company involved.

Some measurement of the importance and rate of learning in each area has been done by sampling studies (via movies, for example), analysis of causes for cost

[4] Judgment factor due to length of time between performance of the same operation, similarity of operations performed on each jig, etc.

variances, etc. More precision might be obtained by testing the proposed importance or "weight" of each factor by rating the "complexity" of each factor (using a scale of, say one to five), combining it with the proposed weight (such as 40% for worker learning, 20% for tooling, etc.) and relating this to empirical results on *overall* learning rates. This may involve multiple correlations and other statistical techniques, but here is a second important area for detailed industry investigation. Some of the results could easily transform our thinking on basic cost functions.

When such questions are settled reasonably well, a simple weighting procedure might be used to determine the composite rate of learning, as:

Area of Learning	Weight of Area	Unit	Learning Per Unit
Worker	40%	543	1.84
Tooling	20	800	1.25
Supervision	15	909	1.10
Parts Design	15	1,111	0.90
Other	10	1,000	1.00
Total	100%	720	1.39

Combining Workcenters

One elementary trap of learning curves calls for mention because of the frequency with which one meets the error in normal practice. That is, one cannot add the curves for two workcenters having different slopes by simply adding the cost values for two unit points and drawing a straight line between them. The sum of two exponential functions is by no means another one, and the error can amount to some 40% in unit cost for intermediate units.

The reason is simple: early in the game the curve with the steepest slope tends to dominate the picture, while later it becomes much less important and the overall slope reflects the second curve. This means a steep slope at the start, gradually shifting to the shallower slope of the second curve.

Productivity Controls

The use of the concept of "standard" cost at unit x (for $x = 1000$, or 50 or anything else) inevitably leads the Industrial Engineer and others to the idea of "efficiency" or "productivity" measurement at each stage of production output. Normally this ratio equals the "standard" cost divided by actual unit cost. This is then used to evaluate shop supervision, and as a major incentive to low performers. The learning curve offers certain complexities in this handling, which are often overlooked.

In essence, since "standard" may be reached at different units for different cost centers and products, and the slopes themselves may differ sharply, productivity targets must be *different* at the same unit output for each. Figure 5 illustrates this.

The difficulty may, of course, be handled simply by relating actual costs at a unit to the normal of forecasted cost for that unit, rather than to the "standard" itself. In this way the percent accomplishment automatically allows for the different conditions in each workcenter, and therefore permits correct comparison between areas.

Setting Manpower Requirements

Certain definite traps in scheduling are defined by careful learning curve analysis. For example, for a crew of 50 operating at a learning curve of 75% with an output starting at 1 per month off one jig, one cannot quintuple the rate of output simply by using five jigs and five crews of the same size without paying a large cost penalty. For *learning is also cut*. Using five jigs, the original cost of the 100th unit, for example, is not attained until well out toward unit 500. The entire cost curve is moved *upward* since the rate of learning is cut sharply although the *slope* of the cost curve remains at 75%.

	Final Assembly	
	One Jig	Five Jigs
Crew Size (to start)	50	250
Days Flow Time	21	21
Monthly Output (units)	1.0	5.0
Learning Slope	75%	75%
Cost of 100 Units (hours)[a]	42,500	77,600

Similar complications affect computation of the production rate attainable by increasing the numbers of jigs and crews. Such shifts obviously must be accompanied by redefinition of work flow and crew assignments in order to redefine optimum learning rates. Optimizing costs in the face of possible shifts of production rate can clearly affect tooling and layout philosophy, and when pressed to its logical conclusions constitutes an operations research problem of the first magnitude.

LEARNING SHIFTS

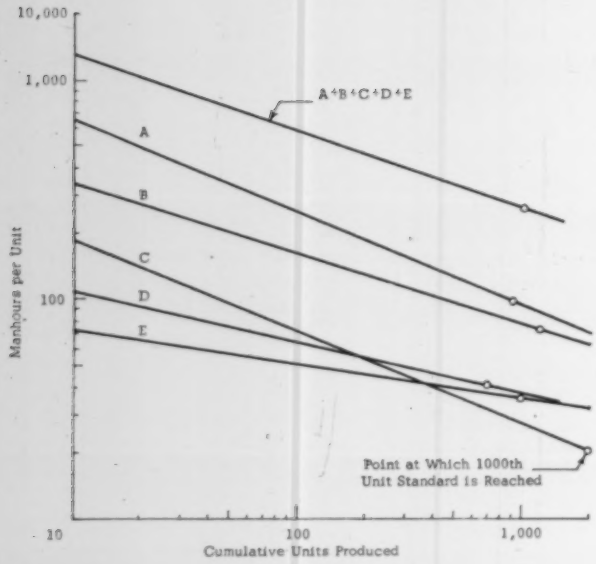
We have now covered most basic elements of learning curve analysis. In the process we have seen a new concept emerge, that of the rate of learning. This concept has been explored briefly to relate it to practical shop control and loading considerations.

But much more can be done with it. We will now probe the possibilities of "shifts" in learning along the same cost function. It will be found that this generates what might be called "non-linear" or "curved" learning curves which are very important in analysis of actual cost effects and trends.

Two principal points will be covered:

1. Changing Rates of Learning.
2. Effect of Task Changes.

[a] C (1000) = 100 hours. This assumes a proportionate cut in learning, which would not quite be the case. There are some benefits through common supervision and jig design which dampen the tendency toward a slower rate of learning.



Products	Productivity at Selected Units 20	50	300	1000
A	20%	30%	63%	105%
B	26	35	64	92
C	14	21	45	74
D	43	53	82	105
E	55	64	83	100
Total	25%	35%	66%	99%

FIG. 5. Productivity Controls.

CHANGING RATES OF LEARNING

In the course of introducing a new product, many conflicting influences are brought to bear on costs. This is especially so where technological improvements are occurring rapidly, where pressure to meet schedule is severe and where lead-times are on the tight side.

Under such circumstances it is important to consider the possibility of shifting rates of learning. Early in production, learning may be confined to learning *how*, more than how to do *better*. The pace then starts to pick up as layout, facilities and other adjustments are completed, and perhaps will accelerate to a "normal" level. However special conditions could generate an actual retrogression or even an extraordinarily rapid rate in learning. For example, an extensive time lag between deliveries of, say, the 10th and 11th units (due perhaps to the need for market or performance evaluation prior to all-out production) easily could cause a loss of learning if the lag were sufficient to require a breakup of production teams. In such a case we might be forced to back up the cost of unit 11 to (perhaps) that of unit 5, with a similar raising of costs for unit 12 and thereafter. Such examples occur not infrequently in production of large, expensive new products.

Figure 6 displays the impact just such an analysis has on a forecast of unit cost. Curve A is the basic cost curve for the workcenter, taken as a linear 70% curve. Curve B represents the *derived* curve of costs projected by considering the matters aforementioned, plus others such as jig realignments, etc. The result obviously is a *non-linear* curve with increasing slope at some times and decreasing at others, having definite peaks and valleys representing specific operating conditions.

Here again we have a concept which calls for further research and testing from the Industrial Engineering profession.

EFFECT OF TASK CHANGES

A second example of non-linear learning appears when we consider the effect of introducing engineering and tooling changes, sizable turnover of labor and supervision or a major rearrangement. Each such major event causes a loss of accumulated learning, and to some extent a return to the unit-one cost level. With engineering changes running heavy in the early stages of production, this often will have a substantial effect on units one through 50. This is illustrated by Figure 7 and the tabulation, which estimate the effect of 10% changes at units 2 and 3, 5% at units 4, 5 and 10, and 20% at unit 20. These data show the effect of changes is somewhat similar to shifts in the rate of learning, in that both reduce the slope of the cost curve and so raise costs significantly.

The hump in Figure 7 at unit 20 reflects incorporation of the 20% change in design. At unit 20 cost jumps to 75% above the "normal" cost level, which illustrates the dramatic effect of a sizable change once production is underway. Even this change, however, becomes of minor importance as production continues and the ratio of those units incorporating the change to all units approaches unity. Improvement is rapid shortly after the change is incorporated, generating a slope of better than 50% (the basic curve has only a 70% slope). This occurs because each additional unit of the new portion represents a large percentage increase in the number of such units produced, which generates a large percentage re-

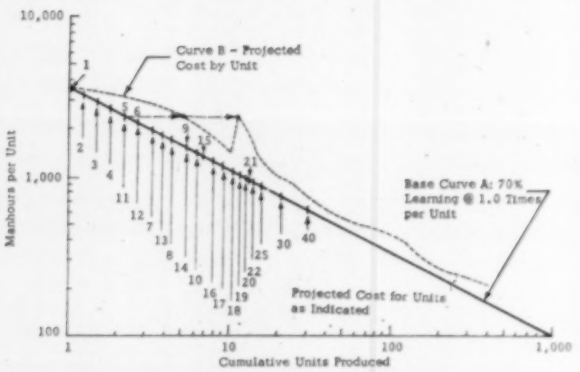
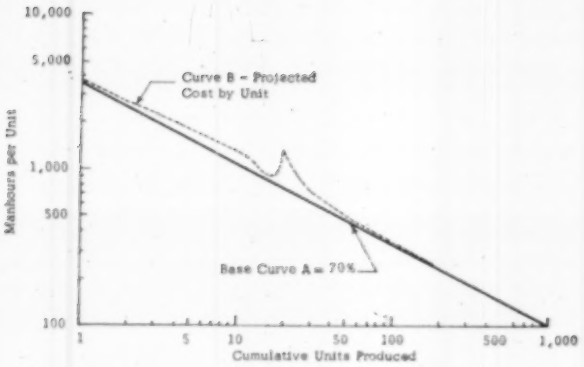


FIG. 6. Changing Rates of Learning. (Factors Affecting *Rate* of Learning: Learning *How*, not How to Do *Better;* Time Lag between Successive Units.)



Unit	Base Cost	Portion of Cost New at Unit Indicated							Total
		1	2	3	4	5	10	20	
			10%	10%	5%	5%	5%	20%	
1	3,600	3,600							3,600
2	2,500	2,250	360						2,610
3	2,000	1,600	250	360					2,210
4	1,750	1,310	200	250	180				1,940
5	1,550	1,090	175	200	125	180			1,770
10	1,100	710	115	122	65	70	180		1,262
20	760	310	78	80	41	43	51	720	1,323
30	620	279	63	64	33	33	37	206	715
50	470	212	47	48	25	25	27	120	504
75	380	171	38	39	20	20	21	89	398
100	330	149	33	33	17	17	17	73	339
200	230	103	23	23	12	12	12	48	233
300	185	83	19	19	10	10	10	38	189

FIG. 7. Effect of Task Changes.

duction in unit cost (the cost of unit 2 is 70% of that for unit one, for example). When this effect is translated to the actual units being produced—say to unit 20—the reduction is much larger than normal at that point (the cost of unit 21 is 97% of that for unit 20) and so the sharp slope appears.

Obviously to combine these *two* effects—slower learning and heavy engineering changes—on early units, can have a major effect on costs. This is actually the case, as will be seen later. In the meantime, it is interesting that the last two illustrations are beginning to look like real experience!

THE S-CURVE

As a matter of experience, early unit program costs often miss the "straight" learning curve level by sizable percentages. Unless a large production run (over 2000 units, say) is planned, this cannot be ignored for pricing or planning purposes without serious financial loss or operational disruption.

We will therefore explore the characteristics of one such cost pattern—a somewhat S-shaped curve—which has become evident in several situations. The existence of this pattern may not be evident to all companies, but it seems of sufficient generality to warrant further analysis and investigation.

Our review will cover:

1. Evidence of the basic S-curve pattern.
2. A simple means of constructing S-curves.
3. Rates of learning in the S-curve.

THE BASIC S-CURVE PATTERN

Considerable actual experience is summarized in Figure 8, and this indicates rather clearly more of an S-curve than a linear function (75% and 80% linear curves are plotted along each product's cost experience for reference purposes, starting from the unit at which "standard" cost should be attained).

The pattern seems to be one where early in each program unit costs run well above the 75% curve, at a slow rate of learning. They then drop rapidly and are even brought below the linear curve, subsequently proceeding at a more gentle slope to the "standard" cost at the prescribed unit. In total, the costs come to about the same for the first 1000 units for either the linear or the S-curve pattern, but their differences can be of major importance. This experience has been roughly comfirmed by informal review of several companies' recent cost experience, and appears compatible with some of the data published on World War II airframe costs (especially the P-51). It is further supported by the frequent comments by production personnel on the need to recognize a trend for costs to flatten out somewhat as unit output gets larger.

The evidence that this pattern is possible means that it is essential to budget labor costs carefully along it. Otherwise the early high level of costs will occur, then the control effort will slack off when costs do reach the normal straight-line level just when they should continue going lower to recover the earlier high-cost position. Just as serious can be the effect of an unrealistically low target for early units, which tends to weaken the confidence of operating personnel in the cost targets and dilute their efforts to meet it.

Several factors appear to contribute to this pattern:

1. The early stages of production are a time of partial experimentation by all personnel. Various approaches are tried in learning to use prescribed tooling and methods, which preclude rapid improvement. Further, last minute changes in design and materials sometimes hit during this period, and these prevent the solidification of techniques necessary for rapid learning or initial low cost.

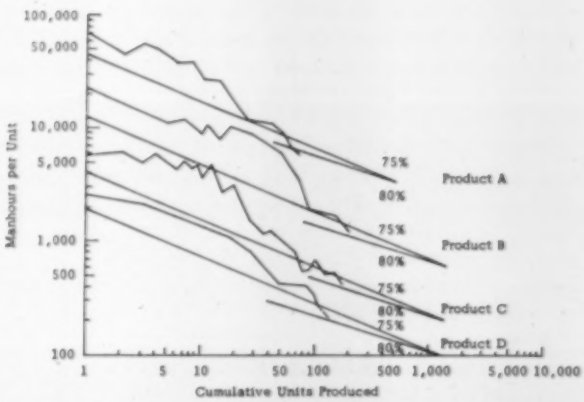


FIG. 8. S-Curve Experience (Assembly Operations).

2. As corrections are made to tooling and methods a rapid reduction in cost is possible for some time. For an assembly operation the learning slope often reaches 50 percent during this period, compared with a norm of 75 percent.

3. Eventually, however, the "water" has been taken out of the costs and we settle down to a more routine activity. The slope of learning now proceeds somewhat more slowly than average, say at 80 percent for assembly.

The exact points at which each stage begins or ends, and the exact slopes of learning, are obviously matters for careful evaluation in each workcenter. However several points at which reasonably clear judgments may be made by Industrial Engineers can be defined, and the development of suitable plans should not be too difficult.

We will now outline one simple technique for constructing such an S-curve. Later we will discuss some of the logic behind this technique.

CONSTRUCTING THE S-CURVE

Review of the experience illustrated in Figure 8 has resulted in the development of an "ideal" S-curve. This pattern does not exactly fit any of the actual curves shown since it is corrected for various operating and accounting problems known to have existed in each. But the result should be a fair approximation to "normal" learning, suitable for use as a tight shop operating target. Specific allowance must be made for special conditions or to get a conservative figure for pricing or other financial decisions. Different company experience or working conditions may well suggest alterations in the shape of this curve, but the general pattern seems to be fundamental.

To be of practical use, the S-curve must be reproducible quickly and accurately. A simple graphic technique is as follows:

Step 1 in the construction is to place the "standard cost" (taken in this example as 100 hours) for unit 1000 at the proper end-product unit in the manner discussed earlier. In the example shown in Figure 8 this is *A*, the Standard Cost Point, and has been placed exactly on unit 1000 for simplicity only.

Step 2 is to draw the learning curve appropriate to the type of work performed. In the example this is assembly, and so a 75% curve is drawn from point *A*. Since this curve is to be a basic reference point for the cost function, we shall give it the name "characteristic curve."

Step 3 is to determine the cost of unit one. This is taken as about 50% more than the cost indicated by the characteristic curve. The exact ratio is a matter of judgment, depending upon the newness of the product to company know-how, the degree of pre-planning to be performed and the early impact of engineering changes on tooling and methods.

Step 4 is to mark off several cost values along the S-curve. Point *C*, the cost at unit 4, is taken at the level indicated by a 90% curve from unit 1 (81% of the cost of unit 1). Point *D*, the cost at unit 10, is taken from the characteristic curve at unit 3, and Point *E* is similarly taken from between units 7 and 8.

Point *F*, the cost of unit 30, is set as the spot where the S-curve crosses over the characteristic curve. This could be varied slightly with different jobs depending on their difficulty or ease.

Step 5 is to establish Point *G*. This point is where the S-curve intersects an 80% curve from Point *A*. It should be moved out or in indirect relationship to point *A*: where *A* is at unit 1000, *G* should be at unit 70; where *A* is at 1500, *G* should be at 105, etc., holding at roughly 7% of point *A* under normal conditions. From Point *G* on, the S-curve follows the 80% line.

Step 6 is to connect all points with a smooth curve.

The Total Cost for the S-Curve Equals That for the Characteristic Curve!

In the case of cost centers whose characteristic curve would be of different slope than 75%, reference lines of correspondingly different slopes are appropriate. Proportions to the amount of learning in a learning curve should be used for this as follows:

	Learning Curve Slopes		
	Assembly	Fabrication	Welding
Characteristic Line	75%	90%	85%
Point *C* Line	90	96	94
Point *G* Line	80	92	88

For assembly, the learning in the characteristic line is 25 points, while that in its Point *C* line is 10 points and its Point *G* line 20 points—or 40% and 80% respectively. Therefore when the characteristic line is 90% as for fabrication activities, since learning there is 10 points it will be 4 points and 8 points for the other two reference lines in a fabrication S-curve.

Tables for cumulative and unit costs for S-curves of various basic slopes may be easily prepared, and some have been. However the S-curve is quickly and accurately drawn.

This S-curve yields a ship-cost curve (using 4 units per ship) with a very high slope for a number of units. Through ship 12 the slope runs roughly 50%, tapering off to 80% by about ship 25. This pattern would only rarely be predicted without the use of such an S-curve technique as discussed here.

It is common practice to consider that assembly and other manufacturing labor costs bear a "normal" relationship to one another. However when this presumption is used to develop a total cost from that of assembly only, a sizable error can be committed. The relationship between these two classes of cost differs widely depending on the number of units produced, even under "normal" cost patterns. Naturally with differences in lead times, this relationship can be distorted in an even less predictable fashion. Without such a distortion the ratio

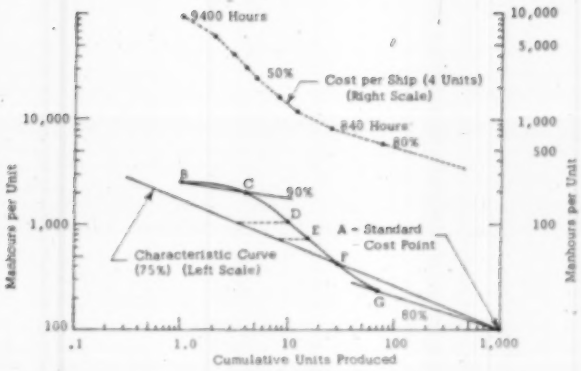


FIG. 9. Constructing the S-Curve.

of fabrication to total cost varies from 7% on early units to 29% at unit 1000.

Obviously the use of an S-curve could generate refinement in the statistical analyses used to measure the influence of various cost elements on the basic rate of learning or the Standard Cost Point *A* in Figure 9. But the rating system described also could be used to explore the placement of Points *B* through *G* and the slopes of the two reference lines used in constructing the S-curve.

RATES OF LEARNING

The S-curve contains an interesting case of changing rates of learning—the concept developed earlier. To explore this, let us compare points on the S-curve with same-cost points on the characteristic curve.

We see the following:

Unit Position on S-Curve	Unit Position on C/C (same-cost unit)	B/A
A	*B*	
10	3	30%
30	30	100
50	74	148
150	225	150
300	385	128
1000	1000	100

But this may also be expressed as shifting rates of learning, by relating increments of unit position:

S-Curve		Characteristic Curve		X/Y
Unit Position	Increment	Unit Position	Increment	
A	*X*	*B*	*Y*	
10	—	3	—	
30	20	30	27	1.35
50	20	74	44	2.20
150	100	225	151	1.51
300	150	385	160	1.07
1000	700	1000	615	0.88

The ratio X/Y is nothing but our rate of learning again. That is, the ratio of the number of units actually produced between two given unit-cost points, to the corresponding number of units read off the straight-line curve. This is simply an application to the S-curve of the idea used in Figures 4, 6, and 7.

TABLE 1

Shifting Learning Rates on the S-Curve

Unit Position on S-Curve		Unit Position on C/C o Same-Cost Unit		Relative Learning Per Unit 1	Slope of S-Curve 2	Amount of Learning 3	Value of b
No. 1	Range 2	No. 3	Range 4	5	6	7	8
1	1	0.37	0.00	0.000	100%	0%	0
3	2	0.50	0.13	0.065	93	7	0.10
5	2	0.85	0.35	0.175	74	26	0.43
10	5	3.00	2.25	0.450	59	41	0.76
15	5	7.50	4.50	0.900	53	47	0.92
20	5	13.50	6.00	1.200	54	46	0.89
30	10	30.0	16.5	1.65	56	44	0.84
40	10	50.5	20.5	2.05	59	41	0.76
50	10	74.0	23.0	2.30	62	38	0.70
70	20	125	51	2.55	67	33	.57
150	80	225	100	1.25	80	20	.33
300	150	385	160	1.07	80	20	.33
1000	700	1000	615	0.88	80	20	.33

1 Ratio of column 4 to column 2.
2 The approximate slope, derived from reading the S-curve at the range indicated.
3 The converse of column 6 (100 minus col. 6).

However this rate for the S-curve reveals an interesting pattern when computed in more detail (See Table 1) and charted on Log/Log paper (Figure 10). We seen to have more than a mere theoretical relationship between two curves. We have seen that there is real meaning to the idea that costs proceeding along a normal straight-line learning curve can hit a period of higher or lower learning. This occurs constantly in practice due to parts shortages, loss of trained personnel, tooling problems or improvements and methods changes, and each time it occurs the curve is either raised or lowered. When this happens in a fairly smooth fashion we obtain a series of cost readings which form a curved line on the chart—as occurs for the S-curve.

This shape makes one wonder whether a formal functional representation would not be helpful. One or more of the many possible functions may well prove to contain elements directly or indirectly relatable to operating parameters. Further research effort could then pin-point the effect of those upon costs, and so permit improved

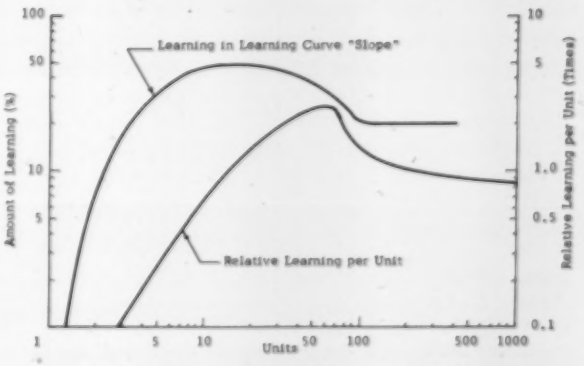


FIG. 10. Shifting learning Rates on the S-Curve.

forecasting and control. The functions then could be used in computer calculation of learning curve patterns for a variety of operating groups and products.

Several functions appear to warrant immediate investigation for fitting to this learning rate pattern:

1. The normal distribution curve with an increasing "stretch" factor for increasing output.
2. An ordinary cubic curve in logarithmic terms.
3. A sine wave in logarithmic terms with a "pinch effect" around unit 70 and a "stretch" factor for increasing volume.

Here again we seem to have a major opportunity for both theoretical and practical investigations. Their results could be of major importance to cost control.

Such formal methods permit more exact determination of C (n) values and therefore might be useful in further theoretical investigation of learning curves.

However, the cruder technique outlined first seems perfectly adequate for normal use in planning and control of costs. Using Log/Log paper, specific judgments on certain key points and a reasonably sound estimate of 1000th item cost, the entire S-curve can be plotted in a couple of minutes for a cost center.

CONCLUSION

We have reviewed certain basic concepts of the Learning Curve as generally understood, and have developed the more straightforward applications to productivity measurement, manpower and space planning, engineering changes, estimating, purchase price analysis and contract negotiation. In the process a new concept has emerged—the rate of learning—which suggests many areas for further analysis and research.

It has also been suggested that an S-curve pattern appears more appropriate than the usual linear Learning Curve. This seems consistent with rate of learning considerations, and the learning rate pattern for the S-curve itself appears interesting as an area for further Industrial Engineering analysis.

Today, the field of learning curve analysis is wide-open for rapid expansion. The concept itself offers great potential for refinement, and this in turn permits more pertinent application to industries other than aircraft or missile production. The probability that this can be done successfully is increased by the growth in importance to our economy of relatively high-cost, low-volume items and by the rapidly increasing technical sophistication of managerial personnel (consider the growing acceptance of operations research and long range planning).

There are many industries or products which come to mind as ready for immediate application of Learning Curve techniques:

Missile Firings

Large missiles involve sizable crews with high pay rates, expensive support equipment and numerous design changes. Opportunities for learning are great, as are the savings from close control.

Missile Base Construction

Installation of bases for Atlas, Titan and Minuteman involves immense costs of a repetitive nature, complicated by many changes in design. Savings from close control could amount to many millions.

Electronic Equipment

Production of large computers, radar installations, etc. could be a sizable field of its own due to the expense involved and the relatively low volume of each major item. Electronics, of course, is able to use components produced to a standard design for a wide variety of applications more than most industries, and Learning Curve analysis must consider this aspect carefully.

Heavy Transportation Equipment

Many types of equipment offer immediate opportunity for evaluation due to high cost and low volume.

Large trucks and trailers
Locomotives
Freight cars
Cabin cruisers
Submarines and other large ships

Building Construction

Large housing projects offer obvious areas for learning, which can be multiplied by proper Industrial Engineering study of work type and flow. Construction of office and factory buildings also would be amenable to the technique, with analysis of work into types and components.

Mass Production Industry

Such industry obviously would not find the Learning Curve of as direct use due to the impact of standardization, mechanization, long production runs and widespread competition on components. However, it can still be used as a check on procurement trends, and in specific areas on relatively low volume products the Learning Curve is quite applicable.

This mass production point is worth further analysis. Let us consider a case where the production costs of major automotive components at unit 100,000 (exclusive of special tools and other fixed overhead) amount to the following:

	Total	Assembly	Fabrication	Materials
Chassis	$ 710	$210	$350	$150
Engine	310	60	150	100
Body and Final Assembly				
A	780	480	200	100
B	1000	600	250	150

The company markets several combinations of these major components, and each is therefore produced in varying quantities for the model year. Assuming Learning Curve "slopes" of 85% for assembly, 94% for fabrication, and 98% on materials, there are many possibilities for the *marginal* cost of each unit.

For cars with widely varying volumes we would have the costs *at the last unit produced* as tabulated at the top of the next page.

There is a drop of 26% *exclusive* of the effects of high volume on fixed costs as volume goes from 100,000 to one million. Naturally the amortization of fixed costs over

	Total Output		
	100,000	400,000	1,000,000
Chassis	$ 710	$ 605	$ 547
Engine	310	272	251
Body Assembly and Final Assembly *A*	780	620	537
Total	$1,800	$1,497	$1,335

the larger volume causes large further cuts in unit cost, but this 26% drop is not to be ignored! This represents many tens of millions of dollars over the total volume produced. But the impact of learning is even more pervasive when we look at smaller volume models within the product line.

Assume that convertibles (Body B) run about 100,000 per year but use the same chassis as other models. Their season is early in the year, so that increased production of convertibles uses chassis built in the 200,000 unit range. Therefore pricing policy and production plans must be geared to anticipated costs at that level. The marginal cost of the 50,000th convertible should give us an idea of the impact:

	Cost/Unit
Chassis (@ unit 100,000)	$ 710
Engine *A* (@ unit 50,000)	332
Body *B* (@ unit 50,000)	1,125
Total	$2,167

This is an increase of $670 over the "normal" unit cost at unit 400,000, of which only $245 is due to the special body. The rest reflects Learning Curve effects due to volume, and is well over one-quarter of the "normal" cost.

An even more extreme case would be for a special low volume model involving a special chassis, engine and body each to be produced for only 10,000 units. Assuming the chassis and engine are 10% more expensive in basic design, and the body is 10% more expensive than Body B, we have the following startling conclusion:

	Cost of Unit 10,000
Chassis	$1,045
Engine	433
Body	1,646
Total	$3,124

This increase of almost $1000 or 50% over the convertible cost is mainly due to lack of learning, and must be *added* to the effect of heavy tooling and space costs on low volume output. It is no wonder that special models often constitute an inordinate drain on profits!

It is hoped that this discussion will stimulate renewed interest in the Learning Curve by all interested in planning and control of costs. The time seems suitable for a concentrated attack on development and use of this powerful tool by both industry and academic personnel.

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Objective Aspects of Computer Facility Design

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COMPUTER facility design is gaining prominence as computer systems continue unprecedented acceptance in scientific and data processing applications. Many phases of computer facility design are compatibly derived from accepted facility design practices. However, facility cost analysis and system layout are design phases which possess unique characteristics and perplexities. This presentation is an attempt to objectively formulate criteria to assist in resolving perplexities inherent to these design phases.

TOTAL FACILITY COST

Scrutinization of various computer systems obviates the significance of facility cost differentials. Consequently, facility costs must be intelligently estimated and considered an integral part of the computer system's initial cost or appropriately prorated to form an equivalent rental expense. This concept implies a more equitable base for initial cost comparisons of various computer systems.

The challenging aspect underlying this concept is the intelligent estimation of computer facility costs. While the purchase or rental costs of computer systems are easily obtainable from vendors, the respective facility costs are considerably more difficult to quantify. A first aproximation to analyzing computer facility costs may be through formulation of a mathematical model simulating the aggregated cost components. Variability of costing rates and facility enables the engineer to study the underlying influences on computer facility costs and derive quasi-optimized macroscopic system layout and facility design criteria.

The total facility cost may be conceived as an aggregation of several cost components. These costs components are generally common to all computer facilities but vary in magnitude depending on specific physical parameters characterizing the computer system. Assuming that a suitable site is available, the following subjectively categorize the cost components generally comprising computer facility costs:

Fixed Facility Costs

1. Cost of relocating facilities presently occupying designated site.
2. Engineering expense of establishing computer facility; i.e., design costs of system layout, air conditioning and electrical systems.

Variable Facility Costs

1. Air Conditioning Costs:
   a. Purchase cost of air conditioning system.
   b. Installation costs of air conditioning system.
2. Electrical Costs:
   a. Purchase costs of isolation transformers and switchgear.
   b. Installation costs of electrical equipment and secondary distribution.
3. Housing Costs:
   a. Purchase and installation costs of elevated flooring.
   b. Purchase and installation costs of acoustical ceiling.
   c. Purchase and installation costs of regulated lighting system.
   d. Purchase and installation costs of insulated partitioning.

A computer system may be characterized by three physical parameters; namely, layout area in square feet (symbolized by A), aggregate heat dissipation in BTU/hr. or equivalent "tons of air conditioning" (symbolized by D) and aggregate electrical power in KVA (symbolized by E). To formulate a mathematical expression describing computer facility costs, the underlying principles utilized are:

1. Purchase costs are quadratically related to system parameters.
2. Installation costs are linearly related to system parameters.
3. The concept of penalty cost is introduced to economically assess expected expansion requirements.

Since the cost components are functionally related to the system parameters, the total facility cost may be expressed as follows:

Total Facility Cost

$$(TFC) = F + a(D) + b(D)^2 + c(D)^{-2} + d(E) + e(E)^2 + f(E)^{-2} + g(A) + h(A)^{1/2} + j(A)^{-1}$$

These cost component representations have the following significance (the coefficients represent estimated costing rates):

F	Total fixed cost of establishing computer facility.
$a(D)$	Installation cost of air conditioning system including installation of ducts and plenums, equipment, steam piping and environmental control wiring.
$b(D)^2$	Purchase cost of air conditioning system including filter section, refrigeration equipment, blower unit, ducts and plenums.

* The concepts presented in this article were formulated while the author was associated with the Cornell Computing Center, Ithaca, New York.

$c(D)^{-2}$ Air conditioning system penalty cost attributable to not satisfying expected expansion requirements.

$d(E)$ Installation cost of electrical power equipment and secondary distribution of electrical services.

$e(E)^2$ Purchase cost of isolation transformers and switchgear.

$f(E)^{-2}$ Electrical power penalty cost attributed to not satisfying expected expansion requirements.

$g(A)$ Purchase and installation costs of elevated flooring, acoustical ceiling and lighting provisions.

$h(A)^{1/2}$ Purchase and installation costs of insulated partitioning.

$j(A)^{-1}$ Housing penalty cost, attributable to not satisfying expected expansion requirements.

Since a relationship exists between the input-output parameters of a computer system; i.e., $k = E/D$, kD may be substituted for E in the above total facility cost expression. By combining similar terms, it then resolves to the following simplified form:

$$TFC = F + g(A) + h(A)^{1/2} + j(A)^{-1} + p(D) + q(D)^2 + r(D)^{-2}$$

where the composite cost coefficients are:

$$p = a + dk$$
$$q = b + ek^2$$
$$r = c + fk^{-2}$$

Hence, the total facility cost becomes a function of two system parameters; namely, layout area and aggregate heat dissipation characterizing the computer system. Estimation of these system parameters poses one rather perplexing problem, that of estimating facility provisions for system expansion. A feasible solution may be obtained by analyzing the facility expansion costs to derive economically justified expansion provisions.

FACILITY EXPANSION COST

Obviously it is not intelligent engineering to design a computer facility which satisfies only present computational demands. Provision for operational flexibility and future expansion must be logically integrated with the present requirements to design a computer facility that is economically justified over a reasonable future period. This is a significant design corollary but because of its inherent perplexity is often quantitatively neglected.

When a computer system is being scrutinized or has been selected, the minimal air conditioning and electrical power requirements plus layout area can be easily derived from the vendor's system specifications. It has been previously implied that the total facility cost represents both present and economically justified expansion requirements. This suggests that the independent variables of the total facility cost expression be divided into two elements representing the present or minimal facility requirements and the facility expansion provisions. If these elements are respectively denoted as A_m, A_e and D_m, D_e the total facility cost expression is transformed as follows:

$$TFC = F + g[A_m + A_e] + h[A_m + A_e]^{1/2} + j[A_m + A_e]^{-1} + p[D_m + D_e] + q[D_m + D_e]^2 + r[D_m + D_e]^{-2}$$

since:

$$A = A_m + A_e \quad \text{and} \quad D = D_m + D_e$$

Now the facility expansion cost expression may be formed by aggregating its respective cost components.

Facility Expansion Cost

$$(FEC) = g(A_e) + h(A_e)^{1/2} + j(A_e)^{-1} + p(D_e) + q(D_e)^2 + r(D_e)^{-2}$$

Economically optimal facility expansion provisions may be derived by taking the first partial derivative of the facility expansion cost expression with respect to A_e and D_e and equating the resulting expressions to zero. Solving these respective expressions for A_e and D_e, the facility expansion provisions which are economically justified have been quantified. The mathematical manipulations inferred are subsequently shown.

$$\frac{\partial FEC}{\partial A_e} = g + \frac{h}{2}(A_e)^{-1/2} - j(A_e)^{-2} = 0$$

$$g(A_e)^2 + \frac{h}{2}(A_e)^{3/2} - j = 0$$

letting $A_e = X^2$; $\quad gX^4 + \dfrac{hX^3}{2} - j = 0.$ Eq. 1.

$$\frac{\partial FEC}{\partial D_e} = p + 2q(D_e) - 2r(D_e)^{-3} = 0$$

$$2q(D_e)^4 + p(D_e)^3 - 2r = 0$$

$$q(D_e)^4 + \frac{p}{2}(D_e)^3 - r = 0 \qquad \text{Eq. 2.}$$

$$E_e = kD_e \qquad \text{Eq. 3.}$$

Eq. 1. is a quartic equation expression the relationship between the estimated cost coefficients and a pseudo-variable representing the additional facility area which is economically justified for future expansion. Similarly, Eq. 2. is a quartic equation which expresses the relationship between the estimated cost coefficients and the additional heat dissipation provision for future expansion. Eq. 3. quantifies the economically justified electrical power provision for future expansion.

Four roots characterize the solution of these quartic optimizing equations. Imaginary roots, usually occurring in conjugate pairs, and negative real roots may be considered trivial solutions. The remaining positive real

roots represent feasible combinations of facility expansion provisions which are economically justified. Generally, selection of the significant positive real roots defining A_e and D_e is not perplexing.

Several mathematical techniques are available to the engineer in solving these quartic optimizing expressions. The normal manual procedure is to reduce the quartic equation to a resolvent cubic equation whose roots are mathematically easier to compute. Or a graphically derived solution would probably approximate the real roots with adequate precision in relation to the precision accompanying the estimated cost coefficients. A more sophisticated method of solution would be to utilize a digital computer program capable of solving a fourth order polynomial expression. Utilization of a digital computer greatly eases the associated numerical analysis; thus increasing the potentiality of this design analysis technique.

With values for A_e, D_e, and E_e derived from the quartic optimizing expressions and A_m, D_m and E_m intelligently estimated from the vendor's system specifications, the independent variables of the total facility cost expression have been quasi-optimized. The influence of the estimated cost coefficients on the total facility cost should be appreciated and correspondingly quantified to represent realistic costing rates. Also, the validity of the underlying mathematical relationships defining the facility cost components should be evaluated in conjunction with estimation of the costing rates. As a by-product of this analysis, the values of A, D and E may be subsequently utilized by the engineer as macroscopic system layout and facility design criteria.

SYSTEM LAYOUT

System layout design commences with selection of that computer system evaluated as meeting the predefined computational objectives most significantly. The importance of sound layout design is rather evident since it becomes the fundamental reference to subsequent facility design phases and is a continual element in the operational efficiency of the system. Consequently, system layout design should optimally resolve the following three aspects:

1. System component orientation to expected applications.
2. Layout restrictions on expected expansion.
3. Influence on facility design requirements.

The layout problem initially resolves to the subjective recognition of paramount restrictions accompanying the computer system's physical and human environment. The most important restrictions influencing system layout design may be itemized as follows:

Physical Site Restrictions

1. Geometry of designated site.
2. Available ceiling height to accommodate air conditioning ducts and plenums and elevated flooring.
3. Arrangement limitors; e.g., I-beams.
4. Heat transfer characteristics of designated site.
5. Floor loading limits.
6. Ability of floor to satisfy intercomponent cabling requirements.

Physical System Restrictions

1. Individual component geometries.
2. Component maintenance areas.
3. Intercomponent coupling.
4. Maximum intercomponent cabling lengths.

Human System Restrictions

1. Manual relationships between operator and input-output components.
2. Visual operator coordination of component displays.
3. Psychological factors:
   a. Component noise level.
   b. Geometrical balance of component arrangement.
   c. Harmony and continuity in expected operator-component relationships.

Ideally the engineer desires a design technique which optimally resolves these recognized restrictions prior to actual system layout design. But this is indeed a challenging and provocative requirement when considering the several restriction categories. In an attempt to reduce human bias and increase layout design efficiency, a feasible approximation to this objective is presented.

From a practical standpoint, the physical layout restrictions are resolved independently of the human restrictions. The suboptimality of this approach is appreciated. Consultation with competent construction engineers will reveal the significant physical restrictions applicable to system layout design. Since this is a common initial procedure to system layout with existing site, its principles will not be discussed further.

A rudimentary objective technique can be formulated to initially resolve the recognized human restrictions of the computer system. Through an analysis of system control, composite priorities are derived which represent the relative control importance of each component comprising the system. This analysis orients the engineer to system layout design since it is predicated on evaluating the operational aspects of the computer system in relation to expected applications.

The paramount human restrictions can be evaluated by analyzing the console operator's visual and manual relationships expected in system operation. It is important that the expected maintenance functions and relationships also be included. Component control, as referenced from the console, is a composite of visual coordinations and manual relationships; each being a function of frequency and importance. This may be expressed as follows:

$$\text{Component control level} = (\text{visual frequency})(\text{visual importance}) + k\,(\text{manual frequency})(\text{manual importance})$$

where: k is a weighting factor

or component control level

$$= \sum_{\text{visual}}^{\text{manual}} \text{(frequency level)(importance level)}$$

To quantify the frequency and importance factors, the following rating scheme may be utilized; 0-trivial, 1-low, 2-intermediate and 3-high. Even though these valuations are grossly quantified, the detail considerations required to derive them initially necessitate the engineer to evaluate the paramount human restrictions. By ordering the control level values in descending order, respective component priorities are obtained for each component comprising the system. The significance of this priority index is to govern component arrangement or orientation in layout design; i.e., the higher the component priority, the more important the visual and/or manual accessibility to the component. Thus, the engineer is confronted with the problem of permuting component arrangement in obeyance with these established component priorities and physical restrictions to formulate an optimal system layout.

Another phase of system layout which remains largely subjective is the evaluation of candidate layouts. However, there are a few analytical parameters the engineer may cautiously utilize to objectively evaluate respective layout merits.

The ratio of system area to layout area provides an index of merit for each candidate layout. This parameter may be expressed as follows:

$$\text{Layout index of merit} = \frac{\text{system area}}{\text{layout area}}$$

where: layout area $\geq$ system layout

$$\text{system area} = \sum_{\text{system}} \text{(physical component area)} + \text{(component maintenance area)}$$

The numerator (system area) represents the aggregate component area and hence remains constant for a specific computer system. If future system requirements have been integrated into the layout, the future components must be included in evaluating the system area. The denominator (layout area) is dependent upon respective system layout design. The value range of this index is between zero and one. An index value near zero characterizes a layout where the layout area is much greater than the system area, while the converse is true of an index value near one.

Obviously, neither of these extreme index values indicates the desired area relationship characterizing an optimal system layout. An index value near zero characterizes a layout overemphasizing provision for future expansion and maintenance area allowances, while the converse is true of an index value near one. Within this range is the optimal layout index value which is quasi-unique for a specific computer facility depending on area utilization and system expansion objectives. This parameter has significance when scrutinizing candidate layouts satisfying only present system requirements versus candidate layouts integrating present and future system requirements.

Console operator convenience is an intangible aspect of layout evaluation but an important continual element in computer system operation. It may be conceived as a function of the aggregate distance in operator-component relationships; each distance being weighted by its component frequency level. This parameter may be termed system accessibility and expressed as follows:

$$\text{System accessibility} = \sum_{\text{system}} \text{(console-component distance)(component frequency level)}$$

System accessibility characterizes the implied console operator's convenience with regard to manual control of the computer system for a particular layout design. The component frequency factor is a usage assessment for each manual control function. A rating scheme identical to that previously presented for control level valuation is applicable in quantifying this factor. The console operator's convenience associated with a specific layout improves as the magnitude of this parameter decreases. However, the absolute magnitude of system accessibility is rather irrelevant and should not be strictly minimized; its importance is in providing comparative differences between candidate layouts designed for identical computer systems.

Although these parameters provide some comparative objectivity in evaluating the merits of candidate layouts, they must be considered in conjunction with implied facility costs, managerial objectives and schedules and many other subjective aspects. Consequently, the finalized system layout represents, at best, a compromise of the many influences which impinge on computer facility design.

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Control Charts for Queueing Applications

by R. W. LLEWELLYN

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IN THOSE instances where queueing phenomena are simple enough to be subject to mathematical calculation, large improvements over intuitively determined solutions are possible. Many authors in this field have recommended that simulation be used before introducing the solution to check the accuracy of the model. It may be important, in some instances, to institute control *after* the installation as well. Control in the form of a control chart will provide warning when the arrival rate or servicing rate has varied sufficiently from those measured originally for an investigation to be warranted. Any change in the situation, such as failure to follow good methods, use of faulty materials or improper equipment maintenance, will be reflected in a change in the service factor and is detectable by control chart methods.

Control chart techniques cannot be borrowed directly from quality control practice. Care must be exercised in setting up these charts because wait-line distributions are badly skewed. On the other hand, calculations can be made so as to show the exact nature of the expected distribution in advance, a factor usually missing in other control chart applications.

Two types of control charts may be constructed on waiting lines. One is a chart on the variable itself (number of machines or customers idle); the other is a chart on the mean number idle in successive groups of observations of equal size. In selecting an example to go along with this discussion, the leading thought was to use one which would yield an extremely skewed distribution of waiting lines. Some queueing models tend to yield distributions that are more amenable to conventional control chart techniques than does the one considered here.

EXAMPLE AND CALCULATIONS

The example selected for presentation is a one-man and m machines situation. One man is assigned to run 20 automatic machines where the service factor (k) is equal to .03. It is assumed that the machines require service at randomly distributed times, that the service times are exponentially distributed and that service is on a first come-first served basis. The formula for determining the probabilities of waiting lines of varying length has been derived elsewhere (2, p. 381):

$$P_n = (m)_n k^n P_0 \qquad \text{Eq. 1.}$$

where

m = number of machines assigned
n = number of machines idle at any instant of time
P_n = probability that n machines are idle at any instant of time
P_0 = probability that all machines are running at any instant of time
k = service factor
$(m)_n = m!/(m-n)!$

The P_n are evaluated in Table 1 for $0 \leq n \leq m$ and plotted in Figure 1. As can be seen, the distribution is extremely skewed, being completely convex (there is no point of inflexion).

CONTROL CHART OF n

In most control chart applications, it is not possible to construct a control chart of the variable itself. It can only be done by gathering enough data to determine the distribution of the variable or by knowing the distribution in advance. In this queueing application the distribution *is* known (Table 1) and can be utilized in setting up control limits. Since $P_0 = .435$, approximately, the lower control limit is clearly zero. It is pointless to mark the "centerline" of the chart, $\bar{n}$. It will be shown later that $\bar{n}$ equals 1.16, approximately, but n can assume only integral values. The upper control limit is all that needs to be determined. The variable can only go out of control at the top, so it is expedient to put the entire critical range

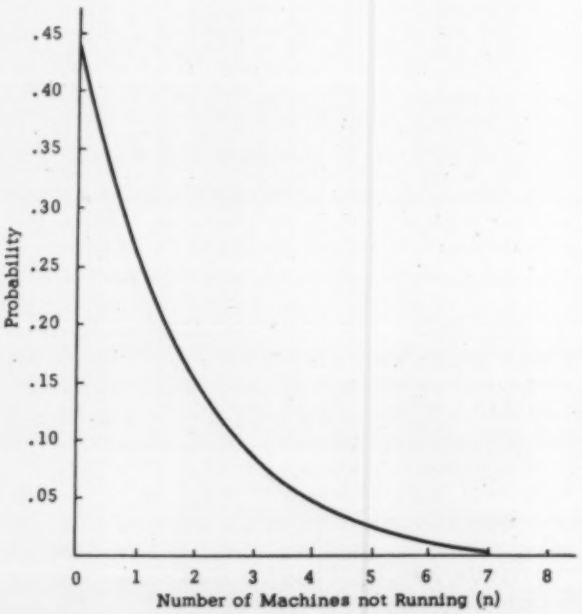

FIG. 1. Probability Distribution of Number of Machines not Running.

TABLE 1

Calculation of P_n and $\sum P_n$

n	$\frac{P_n}{P_0} = (m)_n(k)^n$ $(m-n+1)k$	$\frac{P_n}{P_0}$	P_n	$n=20,\ k=.03$ $\sum_{n=0}^{n} P_n$
0		1.000000000	.434772422	.434772422
1	$20\times.03=.6$	.600000000	.260863453	.695635875
2	$19\times.03=.57$	.342000000	.148692168	.844328043
3	$18\times.03=.54$	.18468000	.080293771	.924621814
4	.51	.09418680	.040949823	.965571637
5	.48	.045209664	.019655915	.985227552
6	.45	.020344349	.008845162	.994072714
7	.42	.008544627	.003714968	.997787682
8	.39	.003332405	.001448838	.999236520
9	.36	.001199666	.000521582	.999758102
10	.33	.000395890	.000172122	.999930224
11	.30	.000118767	.000051637	.999981861
12	.27	.000032067	.000013942	.999995803
13	.24	.000007696	.000003346	.999999149
14	.21	.000001616	.000000703	.99999852
15	.18	.000000291	.000000127	.99999979
16	.15	.000000044	.000000019	.99999998
17	.12	.000000005	.000000002	1.000000000
18	.09	.000000000	.000000000	1.000000000
19	.06	.000000000	.000000000	1.000000000
20	.03	.000000000	.000000000	1.000000000
		2.300053888		

at the upper end of the distribution. It is suggested that we use rather wide control limits, say 3-sigma limits, since the chart will probably be maintained over a relatively long period of time and narrower limits would be violated too frequently for this violation to have any significance whatever. The choice of limits is, of course, arbitrary. We then need to locate the point at which the probabilities sum to .9973. Since

$$\sum_{n=0}^{6} P_n, \text{ from Table 1 is .9941} \quad \text{and} \quad \sum_{n=0}^{7} P_n \text{ is .9978,}$$

the critical point is between $n=6$ and $n=7$. Since n must be an integer, we may use an upper control limit of 6.5, making 6 an expected point and 7 a point out of control.

The usual non-parametric tests cannot be applied to this chart because of the skewness of the distribution. Satisfactory ones can be easily set up, however.

1. $n=4$ or more twice in a row. The probability of this occurring, if the distribution remains stable, is about .0011 or the same order of magnitude as used on the upper control limit.
2. $n=2$ or more five times in succession. The probability of this occurrence is about .0026 or lower.
3. $n=0$ seven times in succession. This probability computes to .0029.

Other non-parametric tests could be devised. Note that the third one cited will permit detection of decreases in the service factor. All of the other tests, including the upper control limit, are tests for increasing service factor.

In order for the application of this chart to be valid, two conditions must be met. First, the observations must be made at random times. Second, the observations must be spaced far enough apart so that the readings are independent. For example, if the service time averages five minutes and if in one observation six machines were idle, one taken ten minutes later would probably show at least four idle. The readings should be far enough apart for a waiting line to be "worked off." In most applications 30 to 60 minutes should be sufficient. One technique to insure both randomness and spacing would be to take all numbers from 45 to 90 out of a random number table, preserving their order, to make up a special table; these random numbers can then be used to space the observations. This would yield an average of 8 observations per day well randomized but never less than 45 minutes apart.

Figure 2 shows a control chart set up as indicated above. To obtain data for the chart, resort was made to simulation. Eighty five-digit numbers were taken from a random number table (1) and listed in Table 2. Since the probability of $n=0$ is .43477, to five significant figures, any number from 00000 to 43477 was taken to represent an observation of $n=0$. On the same reasoning, numbers from 43478 to 69563 were taken to be an observation of

$$n = 1\left[\sum_{n=0}^{1} P_n = .69563\right], \text{ etc.}$$

The chart of 80 points, which might represent 10 days of observations, shows no lack of control, as one would expect from data accumulated in this manner.

CONTROL CHART FOR $\bar{n}$

By grouping observations into samples of size N, it is possible to make control charts on $\bar{n}$. For purposes of this discussion, let us take N equal to 8.

Both mathematical theory and trial and error methods have shown that sample means are normally distributed for sample sizes sufficiently large for any type of parent distribution. In this case, sample sizes of eight should yield means that are approximately normally distributed. Conventional methods of setting up $\bar{X}$ charts should not be used on this chart for two reasons, however. First, the limits can be set more accurately from the theoretical distribution than from an initial set of observations. Second, the use of the range and the multiplication con-

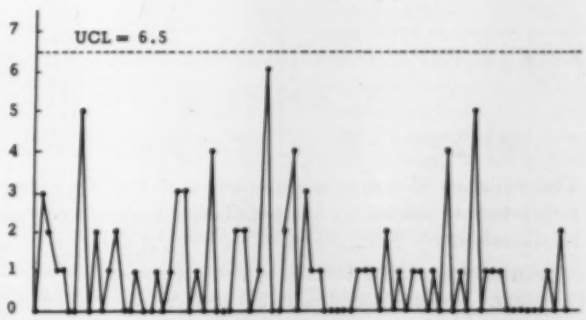

FIG. 2. Control Chart of n.

TABLE 2

Determination of n by Simulation

Reading Number	Random Number	n	Reading Number	Random Number	n	Reading Number	Random Number	n	Reading Number	Random Number	n
1	33713	0	21	48007	1	41	91307	3	61	06991	0
2	85274	3	22	86893	3	42	68434	1	62	94688	4
3	84133	2	23	89640	3	43	48908	1	63	15877	0
4	56732	1	24	16234	0	44	06913	0	64	45197	1
5	65138	1	25	56806	1	45	10455	0	65	16019	0
6	38001	0	26	02176	0	46	12883	0	66	97343	5
7	37402	0	27	96397	4	47	21778	0	67	30976	0
8	97125	5	28	40348	0	48	19523	0	68	59515	1
9	21826	0	29	41134	0	49	67245	1	69	52670	1
10	73135	2	30	42742	0	50	60584	1	70	47377	1
11	07638	0	31	77929	2	51	53853	1	71	41377	0
12	60528	1	32	83411	2	52	24637	0	72	38736	0
13	83596	2	33	35655	0	53	83080	2	73	12451	0
14	10850	0	34	62746	1	54	16444	0	74	24334	0
15	39820	0	35	98952	6	55	60790	1	75	18157	0
16	59580	1	36	06478	0	56	32825	0	76	39527	0
17	38508	0	37	07341	0	57	51981	1	77	50654	1
18	30692	0	38	70668	2	58	47677	1	78	26269	0
19	65443	1	39	95659	4	59	20971	0	79	81749	2
20	27265	0	40	50264	1	60	66281	1	80	31003	0

stants associated with the range assume an underlying distribution that is at least approximately normal. But the center point of the chart ($\bar{\bar{n}}$) the variance of $\bar{n}$ and the control limits can always be calculated if the exact nature of the distribution is given as in Table 1. A general method will be shown which is applicable to any queueing situation, including these for which explicit forms of the mean and variance are not known.

The fundamental equations of the mathematical definitions of the mean and variance of a distribution in the form of the first and second moments, respectively, are (2, pp. 177–178):

$$\mu_n = \bar{\bar{n}} = \sum_{i=0}^{m} x_i f(x_i), \qquad \text{Eq. 2.}$$

where x_i is any score and $f(x_i)$ is the probability of that score, $i = 0, 1, 2, 3, \cdots, m$

$$\sigma_n^2 = \sum_{i=0}^{m} (x_i - \mu_n)^2 f(x_i) = \sum_{i=0}^{m} (x_i)^2 f(x_i) - \mu_n^2. \qquad \text{Eq. 3.}$$

In the symbols of this article, Eq. 2. becomes:

$$\bar{\bar{n}} = \sum nP_n, \qquad \text{Eq. 4.}$$

where the summation is performed over all of the n from o to m. Eq. 3. becomes:

$$\sigma_n^2 = \sum n^2 P_n - \bar{\bar{n}}^2, \qquad \text{Eq. 5.}$$

the summation again applying to all n. Substituting into Eq. 4. and Eq. 5., we get:

$$\bar{\bar{n}} = \sum nP_n = 1.16$$

$$\sigma_n^2 = \sum n^2 P_n - \bar{\bar{n}}^2 = \sum n^2 P_n - (1.16)^2 = 1.9622$$

The variance of means of samples of size N from any population is related to the population variance by the relationship:

$$\sigma_{\bar{n}}^2 = \frac{\sigma_n^2}{N}$$

In our case

$$\sigma_{\bar{n}}^2 = \frac{\sigma_n^2}{N} = \frac{1.9622}{8} = .245275 \qquad \text{Eq. 6.}$$

Then, $\sigma_{\bar{n}} = \sqrt{.245272} = .495$.

Assuming that $\bar{n}$ is normally distributed, the control limits may be found from:

$$UCL_{\bar{n}} = \bar{\bar{n}} + 3\sigma_{\bar{n}} \qquad \text{Eq. 7.}$$

and

$$LCL_{\bar{n}} = \bar{\bar{n}} - 3\sigma_{\bar{n}}. \qquad \text{Eq. 8.}$$

Substituting into Eq. 7 and Eq. 8 gives $UCL_{\bar{n}} = 2.65$ and $LCL_{\bar{n}} = -.325$, the latter result being impossible. So we may take the lower limit as zero and the upper limit as 2.65.

Since the lower control limit did not behave properly, there are three choices of action at this point:

1. Group the observations into larger samples so that the assumption of normality of $\bar{n}$ is more likely to be true. For example, if $N = 16$, the control limits are 2.21 and .11, the lower limit being greater than zero. This would allow a point at about every other day if the average number of observations per day were eight.

2. Keep the sample size at 8, treating the upper and lower limits as approximate. Since the poor behavior of $\bar{n}$ will be associated with the tails of the distribution, the $\pm\sigma_{\bar{n}}$ and $\pm 2\sigma_{\bar{n}}$ points will be more reliable indicators than the $\pm 3\sigma_{\bar{n}}$ points. Nonparametric tests can be based on these points and emphasis in chart analysis directed toward them rather than on points outside the $\pm 3\sigma_{\bar{n}}$ limits.

3. Keep the sample size at 8 and attempt to get more reasonable limits.

a. In this particular example, it is easy to adjust the lower limit. The probability of observing a sample of 8 with all machines running is $(P_0)^8 = .00128$ which is approximately the probability of a point falling at the -3σ point. The probability of having a sample with one observation showing one machine stopped and the others recording all machines running is $8(P_0^7)(P_1)$, reference (2, p. 381). The factor of 8 reflects the fact that there are 8 such possible samples, the observation of one machine stopped appearing in the first, second, third, etc. place in the sample. The probability of this type of sample is .0061, well within the .0013 level. Therefore, we could place the lower control limit at 1/16 (.0625) with the understanding that a point at $\bar{n} = 0$ indicates a point just barely out of control. Placing the limit at 1/16 rather than 1/8 or 0 avoids the possibility of a point falling exactly on the limit line.

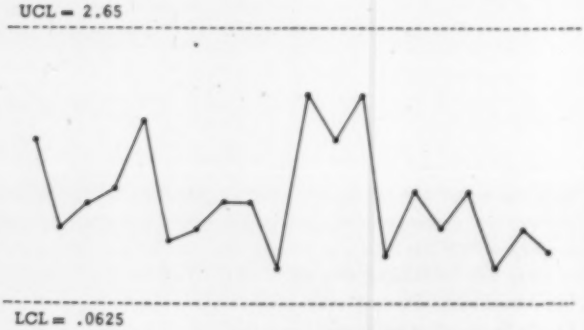

FIG. 3. Control Chart of $\bar{n}$.

TABLE 3

Calculation of $\bar{n}$ from Simulated Data

Item Number	Sample Number									
	1	2	3	4	5	6	7	8	9	10
1	0	0	0	1	0	3	1	1	0	0
2	3	2	0	0	1	1	1	1	5	0
3	2	0	1	4	6	1	1	0	0	0
4	1	1	0	0	0	0	0	1	1	0
5	1	2	1	0	0	0	2	0	1	1
6	0	0	3	0	2	0	0	4	1	0
7	0	0	3	2	4	0	1	0	0	2
8	5	1	0	2	1	0	0	1	0	0
n	12	6	8	9	14	5	6	8	8	3
$\bar{n}$	1.5	.75	1.0	1.125	1.75	.625	.75	1.0	1.0	.375
	11	12	13	14	15	16	17	18	19	20
1	2	1	0	0	0	2	1	1	1	0
2	2	1	3	0	0	0	2	0	2	2
3	2	4	1	0	2	0	0	0	1	0
4	1	0	4	1	0	0	4	1	0	1
5	0	1	0	1	1	0	0	0	0	0
6	3	0	0	0	4	0	0	1	2	1
7	2	3	1	0	3	4	0	0	0	0
8	4	2	7	2	0	0	3	0	0	0
n	16	12	16	4	10	6	10	3	6	4
$\bar{n}$	2.0	1.5	2.0	.5	1.25	.75	1.25	.375	.75	.5

b. The only way of accurately adjusting the upper control limit would be to enumerate the probabilities of all possible samples of $\bar{n}$ up to 2.65 (approximately). The limit could then be established in a fashion similar to the method used for the lower control limit by finding the $\bar{n}$ for which the sample probabilities summed to the 3 sigma level. Unfortunately, such a procedure is prohibitively laborious and must be abandoned. The correction to the upper control limit would probably be slight.

The control chart of $\bar{n}$ is shown in Figure 3 where the limits are .0625 and 2.65. The calculation of the $\bar{n}$'s are shown in Table 3. The first 10 samples are from Table 2, each successive eight observations being grouped into a sample. The second 10 samples are from a continuation of the process of taking numbers from the random number table, the second set of eighty being taken from the point where the first set of eighty terminated.

There should be no attempt to make a chart on the variance or standard deviation of the samples. In the first place, the distribution of the variance of the samples is unknown. Certainly, any chart based on the chi-square distribution would be subject to serious error. In the second place, a chart of subgroup dispersion is not necessary. The parent distribution is anchored to the point $n=0$. Since each P_n is dependent on the magnitude of P_{n-1} they are all changed if P_0 is changed. An increase in the service factor will decrease P_0 and increase both the mean and the variance; this can be detected by the $\bar{n}$ chart. In a similar fashion, a decrease in the service factor will decrease the variance of the distribution and also will decrease $\bar{n}$; the $\bar{n}$ chart will pick it up. Since any significant change in the service factor will be detected in the $\bar{n}$ chart, nothing would be gained by a chart on subgroup dispersion.

SUMMARY

1. Control charts on queueing situations can be made and are useful in warning management that a change in the service factor has been experienced to the extent that some earlier solution to the queueing situation is no longer valid.

2. Such charts may be based on observations of the length of the waiting line (n) or on the means of subgroups of such observations.

3. The calculation of the complete set of probabilities will show the nature of the theoretical distribution. This distribution should be used in setting up control limits.

4. In $\bar{n}$ charts, sample sizes should be somewhat larger than those used on most $\bar{X}$ charts because queueing distribution usually exhibits extreme skewness.

5. Dispersion charts are unnecessary because of the fact that in most queueing situations P_0 is never negligible and the distribution is "anchored" to the point $n=0$. Any change in the service factor that will affect the variance of the distribution will be detected on the $\bar{n}$ or the n chart.

6. It will be remembered that the model used to determine n and $\bar{n}$, the statistics being charted, assumed randomness in both the arrivals rate and the service times. It should be pointed out that violation of the control chart limits or the non-parametric tests *could* be evidence of the introduction of a non-random influence, particularly in the arrival rate, since the statistics charted are sensitive to this type of influence. However, the method of this paper is not suggested as an efficient procedure for determining if a particular queueing situation is behaving in a random fashion. The usual χ^2 test is preferred and should be performed before a decision is made to use a particular queueing model in the necessary mathematical analysis.

REFERENCES

(1) Dixon, W. J., and Massey, F. J., Jr., *Introduction to Statistical Analysis*, Second Edition, McGraw-Hill Book Company, New York, 1957, Appendix, Table A-1.

(2) Feller, William, *An Introduction to Probability Theory and Its Applications*, First Edition, John Wiley and Sons, New York, 1950.

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The Effect of Inflation on Replacement

by **H. G. THUESEN**

Professor of Industrial Engineering and Management, Oklahoma State University

and **P. E. TORGERSEN**

Assistant Professor of Industrial Engineering and Management, Oklahoma State University

IN PERIODS of inflation replacement must, in general, be made at increasing dollar cost. Thus depreciation reserves set up for asset will not be sufficient to buy a like asset on retirement of the first. The purpose of this analysis is to ascertain the effect of a pattern of inflation upon capital recovery of assets.

An inflation rate of k per cent per annum will be assumed so that both dollar values of goods and services and asset replacement cost increase in relation to the expression $(1 + k)^N$, where N is the number of years.

An asset is purchased on the assumption it will provide a service of worth. On a minimum basis the service provided during the life of an asset should equal the cost of the asset. In the process of rendering a service an asset is consumed. The asset is expended piecemeal for the service it renders. For example, assume that an asset operated in a noninflationary period has a first cost of \$1000, a life of 10 years, and no salvage value and that its service has a value of \$100 per year, then: \$100 worth of capital is consumed per year to provide \$100 worth of service per year.

The worth of the service provided by an asset may be more or less than the amount of capital consumed. Where a profit is earned through the joint effect of materials, labor and capital consumption, the portion of the profit ascribable to each of these three items cannot be determined except on the basis of arbitrary assumptions. Commonly, the assumption is made that the worth of the service (at a normal rate of use) provided by an asset is equal to the cost of the portion of the asset that is consumed to provide it. This assumption will govern in this discussion.

EFFECT OF INFLATION

In a period of inflation, and if inflation occurs uniformly to all goods and services, the worth of the services provided by an asset will increase in dollar value.

If inflation progresses in accord with $(1 + k)^N$, a unit of service provided by an asset at the beginning and the end of the first year would have a dollar value proportional to 1 and to $(1 + k)$, respectively. The average dollar value of the service provided during the first year would be proportional to $(1 + k)^{.5}$.

The dollar value of the services provided during the life of the previously described asset, would be as follows:

Dollar worth of service,

$$\begin{aligned} \text{1st year} &= \$100\ (1 + k)^{.5} \\ \text{2nd year} &= \$100\ (1 + k)^{1.5} \\ \ldots &= \ldots \\ (N\text{-}1)\text{th year} &= \$100\ (1 + k)^{N-1.5} \\ N\text{th year} &= \$100\ (1 + k)^{N-.5} \end{aligned}$$

The series above may be re-written as follows:

Dollar worth of service,

$$\begin{aligned} \text{1st year} &= \$100 \times 1 \times (1 + k)^{.5} \\ \text{2nd year} &= \$100 \times (1 + k) \times (1 + k)^{.5} \\ \ldots &= \ldots \\ (N\text{-}1)\text{th year} &= \$100 \times (1 + k)^{N-2} \times (1 + k)^{.5} \\ N\text{th year} &= \$100 \times (1 + k)^{N-1} \times (1 + k)^{.5} \end{aligned}$$

In this series the sum of the middle term is equal to $\frac{(1 + k)^N - 1}{k}$* and thus the

$$\text{Total dollar income} = \$100 \times \frac{(1 + k)^N - 1}{k}\ (1 + k)^{.5}$$

If the first cost of the asset is P, then, for straight line depreciation, the \$100 term may be replaced by $\frac{P}{N}$ and the result is the general expression,

$$\text{Total dollar income} = \frac{P}{N}\ \frac{(1 + k)^N - 1}{k}\ (1 + k)^{.5}$$

For $k = .03$; asset first cost, $P = \$100$; and life, $N =$ 10 years, total dollar income from the asset equals \$1164. Thus the dollar income has been increased by \$164 by inflation. The total dollar return of \$1164 is \$1164 ÷ \$1000 or 116 percent of the first cost. See Table 1 for percentages corresponding to other lives and rates of inflation.

The dollar cost of a like replacement will be equal to $\$1000\ (1 + k)^N$ or $\$1000\ (1 + .03)^{10}$ equals \$1344.

This amount exceeds the dollar income provided by the first asset by \$1344 − \$1164 or \$180.

Also, \$1164, dollar income provided by the first asset is \$1164 ÷ \$1344 = 87 percent of the cost of a replacement. Thus the dollar income provided by the first is

---

* This has the form of the Equal Payment Series Compound Amount Factor found in interest tables.

TABLE 1

Percent of Original Cost Provided by Dollar Income of an Asset for Various Lives and Inflation Rates

Life, in years, N	*5*	*10*	*20*
	Inflation rate, k		
0	100	100	100
.01	102	105	111
.02	105	111	123
.03	108	116	136
.04	111	122	152
.05	113	129	170

sufficient to meet only 87 percent of the dollar cost of its like replacement. See Table 2 for percentages corresponding to other lives and rates of inflation.

EFFECT OF INFLATION AND INCOME TAX

The dollar income provided by the investment in the foregoing example is reduced by income tax on the increased dollar income arising from inflation. Assume that income taxes are determined on the basis of straight-line depreciation.

Then for an income tax rate of t, the dollar income after taxes,

$$\text{1st year} = \$100\ (1+k)^{-5} - [\$100\ (1+k)^{-5} - \$100]\ t$$
$$\text{2nd year} = \$100\ (1+k)^{-4} - [\$100\ (1+k)^{-4} - \$100]\ t$$
$$\cdots\cdots = \cdots\cdots\cdots$$
$$\text{9th year} = \$100\ (1+k)^{N-1.5} - [\$100\ (1+k)^{N-1.5} - \$100]\ t$$
$$\text{10th year} = \$100\ (1+k)^{N-.5} - [\$100\ (1+k)^{N-.5} - \$100]\ t$$

$$\text{Total dollar income after taxes} = \$100\ \frac{(1+k)^N - 1}{k}$$
$$(1+k)^{-.5} \times (1-t) + 10 \times \$100t$$

The general expression is

$$\text{Total dollar income after taxes} = \frac{P}{N}\ \frac{(1+k)^N - 1}{k}$$
$$(1+k)^{-.5} \times (1-t) + Pt$$

For $k = .03$ and $t = .5$ and the asset data given above the:

Total dollar income from the asset after taxes = \$1082. This amount is \$1082 ÷ \$1000 or 108 per cent of the first cost. See Table 3.

The replacement cost will be $\$1000 \times (1 + .03)^{10}$ or \$1344.

Thus the dollar income equals \$1082 ÷ \$1344 or 81 percent of the dollar cost of the replacement. See Table 4.

TABLE 2

Percent of Replacement Cost Provided by Dollar Income of an Asset for Various Lives and Inflation Rates

Life, in years, N	*5*	*10*	*20*
	Inflation rate, k		
0	100	100	100
.01	98	95	91
.02	95	91	83
.03	93	87	76
.04	91	83	69
.05	89	79	64

TABLE 3

Percent of Original Cost Provided by Dollar Income of an Asset for an Income Tax Rate of .5 for Various Asset Lives and Inflation Rates

Life, in years, N	*5*	*10*	*20*
	Inflation rate, k		
0	100	100	100
.01	101	103	105
.02	103	105	111
.03	104	108	118
.04	105	111	126
.05	106	114	135

TABLE 4

Percent of Replacement Cost Provided by Dollar Income of an Asset for an Income Tax Rate of .5 for Various Asset Lives and Inflation Rates

Life, in years, N	*5*	*10*	*20*
	Inflation rate, k		
0	100	100	100
.01	97	93	86
.02	93	87	75
.03	90	81	66
.04	87	75	58
.05	84	70	51

The foregoing results will be altered some, but not greatly by use of depreciation methods which provide for more or less early depreciation than the straight line method.

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Marine Containerization, Caution!

by **GERALD A. FLEISCHER**[1]

Research Manager, Hawaiian Marine Freightways

CONTAINERIZATION has become an important concept to cost-conscious Industrial Engineers involved in today's transportation systems. Current literature has, for the most part, focused on the attractive and economical features of this relatively new concept. However, although containerization admittedly offers many advantages under certain conditions, are there not other conditions under which the costs associated with the process might mitigate, or perhaps negate, the advantages? What is the economic importance of capital expenditures on containers, for instance? How sizeable are the costs of putting freight into a container? What is the economic value of reduced stevedoring costs due to the increased stevedoring productivity which should result from containerization? Normally, the economic feasibility of a system is the decisive factor in weighing the economic acceptability of that system.

The transportation cycle discussed herein involves land-sea-land elements—i.e., domestic shipper to overseas consignee (and return). Recent containerization literature seems to have confined itself to analysis of the marine phase of this door-to-door cycle. But, since all cargo must somehow be transported to the pier (except in the uncommon situation of shippers located adjacent to the pier of vessel loading), other forms of transportation such as rail, truck, etc., are as crucial to the container cycle as the vessel. Therefore, the costs associated with those activities which occur before the outbound freight arrives (and after the inbound freight leaves) the marine terminal cannot be neglected in any evaluation of the overall profitability of containerization in terms of service and economies.

In this discussion, the following apply:

1. The analysis assumes operation of standard cargo vessels—C-2, C-3, C-4, Mariners, etc. Although cellular container ships, roll on-roll off ships and sea-trains appear extremely attractive under certain conditions, the industry has shown a reluctance—probably because of the high initial cost—to effect a rapid transition toward specialized vessels.

2. This presentation does not result from a large scale statistical survey, but rather from personal experience with a West Coast land-sea-land system. Numerical values have been altered without affecting their realism.

3. Containerization *costs* are emphasized on the assumption that the savings from containerization have already achieved their fair share of publicity.

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CONTAINERIZATION SAVINGS

Although this article addresses itself primarily to those economic disadvantages associated with containerization, it would not be prudent to proceed without first discussing some major economic advantages in order to acquaint the reader with both sides of the question. In keeping with the tenor of the article, however, the advantages are discussed critically.

INCREASED LOAD AND DISCHARGE PRODUCTIVITY

Substantial evidence supports the claim that containerization of freight increases load and discharge productivity at the vessel. (By "productivity" is meant amount of cargo handled per unit of labor time—e.g., short tons per gang hour.) Many steamship lines report considerable productivity gains upon replacing loose stow with containerized cargo.

Higher stevedoring productivity is, of course translated into lower stevedoring costs, all other factors remaining equal.

REDUCED VESSEL VOYAGE TIME

Reduced stevedoring time required to handle a given load of containerized cargo means decreased time in port for the vessel transporting such cargo. As turnaround time is shortened, the vessel is capable of making more voyages per year.

Possession of a vessel, whether chartered or owned, entails a considerable fixed cost outlay. If such an increase in number of voyages is effected and the amount of annual cargo available to the carrier is variable, annual fixed operating costs can be spread over a larger volume, thus reducing fixed operating cost per ton.

Available tonnage is not always increased in direct proportion to an increase in vessel tonnage capacity, however. Cargo volume in a particular trade might be constant or nearly constant. If such is the case, the steamship operator does not increase his annual tonnage with an increase in number of voyages— or the tonnage increase would be quite small. Recent containerization literature seems to have assumed perfectly elastic supply although the validity of such an assumption is doubtful.

It might further be argued that, should annual cargo available to the carrier remain constant, the number of vessels operated could be reduced. But this position is valid only if vessel requirements can be reduced by integers. If vessel requirements are reduced by one-third

of a ship, for example, the prospect of discarding one whole vessel from a fleet becomes unrealistic.

DECREASED INSURANCE CLAIMS

Another advantage claimed for containerization is a decrease in insurance claims paid for cargo damage. Containers protect cargo from the elements, handling equipment, bruising by other cargo and many other sources of cargo damage. In addition, the security of the container reduces the chances of pilferage.

REDUCED COSTS OF RECEIVING AND CHECKING

Costs incurred at the marine terminal for receiving and checking freight are substantially reduced when only the container need be received and checked instead of the individual items of freight within. Less labor is required to receive and check one large unit than is required for many small packages.

ATTRACTIVENESS TO SHIPPERS AND CONSIGNEES

A more intangible attraction for shippers and consignees is often the lower tariff rates which certain carriers publish for containerized cargo. This item will be discussed further as a "cost" of containerization.

MISCELLANEOUS ADVANTAGES

The advantages of containerization discussed are by no means inclusive. For a more exhaustive list, see (1) (2). These miscellaneous advantages of containerization will not be discussed either because they are not of economic significance or because there are little relevant supporting data available.

CONTAINERIZATION COSTS

Although authors of recent containerization articles have repeated often the advantages to be derived from containerization, they have paid scant attention to cost elements incurred in order to win these savings. Again, most of these articles were written by persons primarily concerned with the marine phase of the transportation cycle—the phase which accrues most of the advantages (e.g., loading and discharge productivity at the vessel) and few of the costs (e.g., necessary capital equipment). Examination of all elements in the container cycle reveals some disturbing costs.

CAPITAL EQUIPMENT

First, containerization is a process which demands an abundance of capital equipment—containers, highway or rail transporting units, and containerization and decontainerization facilities. Special shipboard and dockside cranes must be purchased or rented if container weight exceeds the capacity of shipboard running gear. In some cases special forklifts or other mechanized equipment must be provided to maneuver containers on the dock or in the hold of the vessel. Finally, certain types of capital equipment—e.g., anchor devices for on-deck containers—must be made available for handling containers throughout the transportation system. Capital equipment costs associated with filling and emptying containers are discussed later.

FILLING AND EMPTYING CONTAINERS

The functions of putting freight into the container before the voyage (and removing freight from the container after the voyage) not only entail considerable direct labor costs but also a sizeable outlay for supervision, clerical labor, and such capital equipment as forklifts and container facilities. The costs of filling and emptying containers varies according to the choice of physical areas where these functions are performed. Containerization may occur at:

1. Shipper's or consignee's warehouse.
2. Some facility removed from the marine terminal such as a container station or railway siding.
3. The marine terminal.

Despite a liability of higher costs, specialized container stations exist because:

1. The shipper or consignee may not have the time, labor or equipment to containerize.
2. Carriers employing Teamster labor may not containerize at the marine terminal because they want to avoid using longshore labor.
3. Other geographic, physical and political factors might influence a decision to containerize at a separate facility.

DRAYAGE

When the container facility is at a distance from the marine terminal, an additional cost element of drayage is interjected into the transportation cycle. Whereas shipments of loose stow freight are hauled directly from the shipper to the marine terminal, or from the marine terminal to the consignee, container-bound freight must first be drayed to the container freight station. Then, after it is containerized, the freight must be drayed to the marine terminal. Even if the shipper containerizes (or consignee decontainerizes) the freight in which case the loaded container is drayed directly from the shipper to the marine terminal (or from the marine terminal to the consignee), there is an additional drayage cost of delivering the empty container to the shipper (or returning the empty container from the consignee). Figure 1 illustrates these movements.

MAINTENANCE AND REPAIR

A container, while protecting cargo, is itself subject to rough handling in the maritime trade. For example, the positioning of containers by forklifts below deck on the vessel is unfortunately not the smooth type of operation likely to be encountered in manufacturing industries. Marine cargo handling may be undertaken with materials handling equipment underpowered to properly handle certain loads since load sizes are continually

fluctuating despite efforts to restrict types of containers in container fleets.

Configuration of vessels also affects the extent of container damage. Since below-deck areas are not rectilinear on most standard cargo vessels, containers are often rammed or "bulled" into position in an effort to maximize cube capacity. Plywood and metal containers are particularly susceptible to damage from this ramming. Sufficient data are not presently available to allow for an accurate estimate of container damage costs (containerization is still a relatively new business). Yet some cases have been observed where units costing $600 have been 50 percent damaged in less than six months of operation. Some $1800 units have been observed to suffer as much as 25 percent damage in a like period. Such observations suggest that the price of maintenance and repair of containers might, on the average, be significant.

TARIFF DIFFERENTIALS

A more subtle cost of containerization arises out of the tariff differential offered for containerized cargo. Some carriers, won over by optimistic containerization literature and acting with imperfect knowledge of the full costs, have published container tariffs with rates lower than corresponding loose stow rates. As a result, these carriers find themselves in the contradictory position of offering a premium service at a bargain rate; for this service may well be more costly to the carrier than if he carried the same cargo under the standard loose stow method. Likewise shippers, convinced by literature favorable to containerization that containerized cargo is considerably cheaper for the carrier to transport, have expected the carrier to pass along his savings in the form of reduced tariff rates. If the carrier derives less revenue from containerized cargo than from the same cargo carried as loose stow, the difference between these two revenues amounts to a "cost" which the carrier is paying for containerization. However, this "cost" is not applicable to the entire transportation cycle. Whereas the tariff differential means a higher cost for the carrier, it affords a like savings to the shipper.

PRODUCTIVITY SHARING

Another implied containerization cost results from the concession on the part of carriers to the demand of the longshore labor unions for a share in the increased productivity effected by containerization. Longshore unions are well aware that increased productivity means reduced costs and that management is eyeing containerization as a principal source of future increased productivity. Unions can hardly be expected to welcome any innovation which might bring about a reduced labor force or fewer work hours for the present membership. However, union leaders have indicated that they will not oppose containerization as long as they can somehow share in the benefits. West Coast longshoremen (ILWU) have recently signed an unprecedented[2] contract (9) affirming the union's right to a share of the dollars saved because of increased productivity. It may be assumed that longshore unions elsewhere will follow suit and, should this be the case, the shared dollar must be numbered among the costs of containerization.

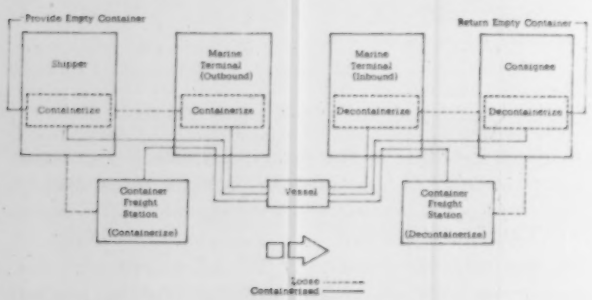

FIG. 1. Flow of Containerized Cargo.

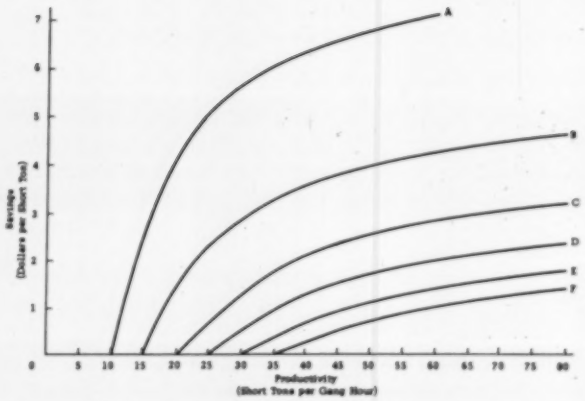

FIG. 2. Savings in Stevedoring Costs Due to Increased Productivity (Based on Average Hourly Gang Costs of $85.00).

QUANTIFYING SOME PRINCIPAL SAVINGS AND COSTS

Thus far certain costs and savings have been discussed in general terms. This section will present some of these costs and savings quantitatively, using hypothetical, but not unrealistic, situations.

REDUCED STEVEDORING COSTS

As indicated earlier, the primary advantage claimed for containerization is reduced stevedoring costs. The effect of increased productivity on stevedoring costs is shown in Figure 2. Algebraically, the figure is derived as follows:

Let:

P_1 = Productivity *before* containerization

[2] Unprecented, that is, in the maritime industry. Precedence exists in the recent contract between Armour and Company and Amalgamated Meat Cutters and Butcher's Workmen and United Packinghouse Workers' unions.

P_2 = Productivity *after* containerization (Presumably $P_2 > P_1$)
K = Average cost per gang hour
C_1 = Cost per ton *before* containerization
C_2 = Cost per ton *after* containerization
S = Savings in dollars per ton

Then:

$$S = C_1 - C_2$$
$$= \frac{K}{P_1} - \frac{K}{P_2}$$
$$= \frac{K(P_2 - P_1)}{P_1 P_2}$$

This figure shows the savings in dollars per short ton that may be obtained by increasing productivity from various initial situations (based on average hourly gang costs of $85.00). For example, line "B" illustrates the savings possible through increasing productivity over an initial (before containerization) productivity of 15 short tons per gang hour. It is apparent that, as productivity increases, savings increase at a decreasing rate. If the initial (pre-containerization productivity) is low, the greatest dollar gains are made at the early stages of a system change. Again, referring to line "B" in Figure 2, $2.84 per short ton may be saved if productivity is increased from 15 to 30 short tons per gang hour. However by increasing productivity from 30 to 45 short tons per gang hour (line "E"), only $0.94 per short ton can be saved. Thus containerization has less economic justification at high initial (pre-containerization) productivity levels. At these levels the costs necessary to achieve further increases in productivity become progressively important.

COST OF CONTAINER

Container amortization cost becomes considerably more meaningful when it is applied to tonnage carried by that container. For example, consider a large container having an initial cost of $2,000, salvage value of $200, and a six-year life. Based on straight line depreciation, the annual depreciation charge for this carrier would be $300. (Interest rates are ignored in order to simplify the example.) Next, assume that the container is capable of carrying 10 short tons of cargo one way but, due to trade imbalance, averages only 15 short tons per round trip. If this container makes 12 round trips per year, it carries 180 short tons annually. Amortization as applied to tonnage in this case amounts to $1.67 per short ton. Note that under certain conditions this cost alone may seriously mitigate the savings in stevedoring costs.

CONTAINERIZING COSTS

The costs associated with filling and emptying a container are significant. Assume checking, receiving, and freight-to-container productivity to be at the rate of 1,800 pounds per man hour (a productivity rate not uncommon in dry freight truck terminals). Again assume an average labor cost of $3.00 per man hour. The cost of putting freight into this container would be $3.33 per short ton. It is also highly probable that the cost of decontainerizing the freight would be about the same.

DRAYAGE

The schematic of Figure 1 shows the additional drayage element necessitated by containerizing at a container station noncontiguous to the marine terminal. The actual cost of drayage, of course, depends upon the distance between the container freight station and the marine terminal. As a specific example, assume a container freight station located two miles from the marine terminal. Also assume that the vehicle which transports the freight from the container freight station to the marine terminal carries a load of ten short tons one way and returns empty. If the cost of this trip (including labor, vehicle depreciation and fuel) is $5.00 per trip, an additional cost of $0.50 per short ton has been introduced by extra drayage. From experience, this figure is highly conservative.

SUMMARY AND CONCLUSIONS

At this point a question might arise as to why carriers use containerization. First, a carrier might containerize because a systematic overall analysis of his own particular situation may reveal containerization to be economically advantageous. Second, a decision to containerize could result from a failure to recognize the full costs involved. Third, carriers may be forced into containerization by competition. Shippers who are naturally attracted to the multi-advantages of containerization (e.g., decreased damage, lower tariff rates) are likely to patronize the carrier offering this service. Thus containerization becomes a matter of survival instigating a spiralling trend towards containerization by all carriers in the trade without regard to the ultimate effect on costs in the transportation cycle.

Fortunately, as cost data are being developed, those responsible for containerization are becoming more discrete in their use of it as a panacea for all their cargo handling ills. A few public and private groups have begun to realize that containerization is not the boon to transportation that was originally claimed, but that it is a complex phenomenon which should be employed only in those areas where it has a true economic advantage. An intelligent and perceptive analysis of both the savings and costs of containerization systems could halt a dangerous "buy now, pay later" trend which seems to be underway.

REFERENCES

(1) Carrabino, Joseph D., "Containerization," prepared as Report 57-56, An Engineering Analysis of Cargo Handling—VI, UCLA, Los Angeles, July 1957.
(2) Cabbabino, Joseph D., "Determination of Optimum Sizes

and Economic Feasibility of Shipping Containers Using Operations Analysis Techniques," *Journal of Industrial Engineering*, November-December 1958.
(3) DAVIS, HAROLD, AND WEINSTOCK, JACK, "Analysis of Stochastic Model of Cargo Handling," prepared as Report 56-34, An Engineering Analysis of Cargo Handling—III, UCLA, Los Angeles, July 1956.
(4) O'NEILL, RUSSELL R., "Simulation of Cargo Handling Systems," prepared as Report 56-37, An Engineering Analysis of Cargo Handling—V, UCLA, Los Angeles September 1956.
(5) PARKHURST, R. B., "The Industrial Engineers' Concept of Productivity," *Journal of Industrial Engineering*, September-October 1958.
(6) *Cargo Ship Loading*, Publication 474, Maritime Cargo Transportation Conference, National Academy of Sciences, National Research Council, Washington, D.C. January 1, 1957.
(7) "Field Study of 1953, the Department of Engineering," prepared as Report 55-2, An Engineering Analysis of Cargo Handling—II, UCLA, Los Angeles, November 1954.
(8) "Maritime Transportation of Unitized Cargo," Maritime Cargo Transportation Conference, National Academy of Sciences, National Research Council, Washington, D.C., June 30, 1959.
(9) "Memorandum of Understanding between Pacific Maritime Association and International Longshoremen's and Warehousemen's Union," a summary of items agreed to by the parties in the 1959 negotiations as amendments to the 1958 ILWU-PMA contracts.
(10) *The NEAC Study*, Publication 389, Maritime Cargo Transportation Conference, National Academy of Sciences, National Research Council, Washington, D.C., December 28, 1955.
(11) *News Letter, No. 11*, Maritime Cargo Transportation Conference, National Academy of Sciences, National Research Council, Washington, D.C., November 1, 1958.
(12) *Recent Research in Maritime Transportation*, Publication 592, Maritime Cargo Transportation Conference, National Academy of Sciences, National Research Council, Washington, D.C., February 13, 1958.
(13) *The SS Warrior*, Publication 339, Maritime Cargo Transportation Conference, National Academy of Sciences, National Research Council, Washington, D.C., November 30, 1954.

A Time Formula Solution for Air Force Rewarehousing Standards

by **DAVID W. ANDERSON**

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and **ROBERT K. CAVE**

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HILL AIR FORCE BASE, Utah, is the home of the Ogden Air Matériel Area—a logistic support complex that serves seven western states and has world wide control over many prime weapons systems. Within the organization of OOAMA, as the Ogden Air Matériel Area is known, are five directorates of which the Directorate of Supply and Services, is one, employing some 2,200 people. The Supply Directorate's mission is to provide supplies and logistical services to Air Force units throughout OOAMA and in certain prime classes throughout the world.

In performing this mission, about 600,000 different items are stored in warehouses and an activity of 11,653 items per day are debited or credited. These items amount to 1403 tons of material that are moved in and out of the warehouses during a normal daily operation.

There are many items, however, whose activity changes from time to time, and often it is more advantageous to move items to or from towveyors, apron conveyors, or other restricted mechanized conveyances so that all active items are in the proximity of mechanized equipment. It is this movement of items to another warehouse or within the same warehouse that we term rewarehousing.

EARNED HOUR REPORT

The regular handling of material whose movement is caused by a normal receipt or shipment is covered by engineered labor standards, and the results of labor activity in receiving or shipping items is reported on an "earned hour report," which shows the labor utilization in the particular work center. To date, there has been no satisfactory standard set on rewarehousing—the reason for this being the non-standard materials handling practices used in moving the material to a new warehouse location.

In order to allow "earned hour credit" for performing the rewarehousing workload, a system had to be designed, not only to account for the work content of the job, but to count the elements of work as it is performed, so it could be reported in a mechanized reporting system shortly after the work was performed. Of course, the cost of performing the accounting function had to be within

the bounds of normal economy.

Past time study experience showed our methods and standards staff that average times or modal times to rewarehouse a location did not represent accurately the earned hours in the rewarehousing function for a two week report period.

REWAREHOUSING STANDARD

At the annual Industrial Engineering Seminar sponsored by the Salt Lake Chapter of AIIE, a lecture on Universal Maintenance Standards was given by Dr. H. B. Maynard of H. B. Maynard and Company, Inc. The authors attended that session and decided to apply Dr. Maynard's principle to the rewarehousing problem. Since rewarehousing is a non-repetitive type function, we used Dr. Maynard's theories and developed a "work-order" type rewarehousing standard based on MTM standards and our own standard data.

The system briefly works like this: When a major rewarehousing project is conceived, a work order is established and a time study analyst is called to look at the job. Using a set of predetermined time formulas, the Analyst tailors an engineered standard to match the best method of moving the property as determined by the storage specialists. As the property is moved to the new location, an AF Form 227 "Change Location Card" is accomplished for each commodity being transferred. The total job time is divided by the number of line items (stock items)to assign a pro-rated time value to each Form 227 "Change Location" that is turned in to the Production Control Office. Production Control then credits the warehouse with earned hours as they receive the 227 Forms.

The necessity of setting a rewarehousing standard grew from the fact that about half a million dollars per year is spent in rewarehousing property to allow for greater savings in materials handling of items that have a greater turnover. An accurate measure of effectiveness leads the Storage supervisors to problem areas and methods improvements. In justifying manpower the standards are invaluable where reductions in force tend to be made indiscriminantly. In addition, manpower planning of rewarehousing projects can be made more scientifically by using the formulas.

CATEGORIES

The standards were broken into three different categories, for bulk, box pallet, and bin stock material. We designed a standard for moving property from one warehouse to another, and within each warehouse and for each of the above categories a standard for removal from the location and storing the property. In essence nine standards have been established and are available for use when the variables are plugged into the time formula. The formula represents an approved method of moving stock in the warehouse, however warehousemen may vary technique if conditions permit further economy steps.

AN EXAMPLE

As a matter of example let us examine, in detail, the standard established to cover the rewarehousing of bin stock items from the losing location to the door.

Bin stock is warehoused with a stock item (one AF stock number) in each bin location. Normally, when moving, the material is removed from the bin and to prevent loss is placed in sacks or larger boxes depending on the material configuration. Generally two sacks are filled, that is, two locations are emptied before the warehouseman carries the two bags or boxes to a flat pallet or "egg crate" that has been set at the end of the bin row. This is repeated until all the bin locations are emptied. An extensive sampling study shows that the material from twenty locations can be stacked on one flat pallet or "egg crate." As the pallets are loaded, a fork lift truck carries the material to the new locations or to a flat bed truck depending on the new location and an AMC Form 227, "Kill Location," is prepared and sent to the locator office.

When the material arrives at the new location it is loaded out by fork lift and carried to the end of the bin row where a warehouseman carries it to the new bin location two bags at a time.

The development of the time formula to accomplish a bin rewarehousing job is as follows:

No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Time to pull bag or box full of property (1 location)	Place in bag or box	Carry Item to Pallet	Carry Pallet To Truck	Obtain Flat or Safety Pallet	Prepare Kill Location 227 Whse	Prepare Kill Location 227 Whse	Make Up Carton	Check Stock Number	Prepare Part Tag 50B
.040	.075	.177	.5792+ travel	.2758+ travel	.739	.481	.522	.021	.845

Study No. 1—Pull bag or box filled with property (one location, one line item). The standard, .040 minutes, is for pulling the carton from the shelf and placing it in the collecting box. The dependent variable here is the number of items N removed from the shelf.[1]

Study No. 2—Place carton or items in bag or collecting box. The time .075 minutes per piece is the sum of all times for removing one unit from the shelf. The variable is N, the number of boxes pulled.

[1] Sample ½ of bin locations, count number of units in each bin, use average number of units per bin times line items to be pulled as N for the job.

Study No. 3—Carry item to pallet. The warehouseman carries the property from two bin locations to the flat pallet. We call the total property in one bin location a line item. In this case 15 steps at 17 TMU per step × 2 for return trip = .177 minutes per line item. The *LI* (stock item) acts as the variable in our time formula.

Study No. 4—Carry pallet and load to truck and load. Travel is calculated from fork lift standard data. The time to run a fork lift is .0023 min. per foot traveled f_t. The total standard is then .5792 + travel + .209 obtain lift or .209 + .5792 + .0023 (f_t) where f_t is the distance to the loading dock.

Study No. 5—Obtain flat or safety pallet .2758 + travel or .2758 + (.0023) f_p where f_p is the distance between the end of the bin row and where the pallets are stacked.

Study No. 6 and No. 7—Prepare AF Form 227. Part of the form is prepared in the warehouse, the other is prepared in the warehouse locator office.

Source	
Timestudy	.739—Kill location in warehouse
Timestudy	.481—Locator work
	1.220

In rewarehousing an AF Form 227 is accomplished for each line item rewarehoused. The variable in the time formula is *LI*.

Study No. 8—Make up cartons. This depends upon the number of line items or bin locations that are emptied. Cartons sometimes (½ of the time) have to be made up to receive bin stock. *LI* is again the variable applied to this time.

Study No. 9—Check stock number. This time allows for checking accuracy of stock number on material to be moved. The variable is each line item.

Study No. 10—A part tag is prepared for each *LI* and is sent with the material to the gaining warehouse. To

Task	Time	Variable
1. Pull Property	.040	*N*
2. Place in bag or box	.075	*N*
3. Carry to Pallet	.177	*LI*
4. Carry to truck & load, return to bin	.5792+travel	f_t
5. Obtain Safety or Box Pallet return to bin	.2758+travel	f_p
6. Prepare paperwork "Kill Location" in Locator Office	.481	*LI*
7. Prepare paperwork "Kill Location" in Warehouse	.739	*LI*
8. Make up cartons	.522	*LI*
9. Check Stock Number	.021	*LI*
10. Prepare Part Tag 50B	.845	*LI*
11. Obtain fork lift	.209	—

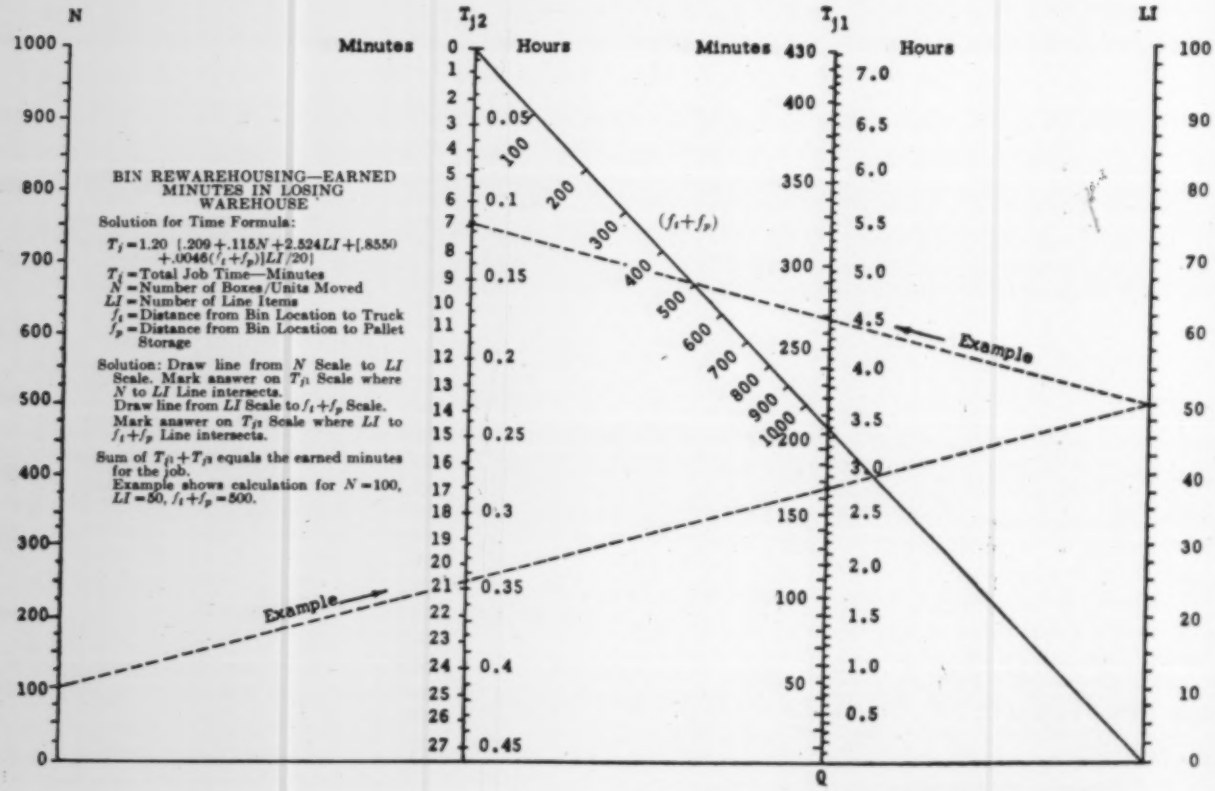
N
Minutes
T_{j2}
Hours
T_{j1}
Minutes
Hours
LI
BIN REWAREHOUSING—EARNED MINUTES IN LOSING WAREHOUSE
Solution for Time Formula:
$T_j = 1.20\ \{.209 + .115N + 2.524LI + [.8550 + .0046(f_t + f_p)]LI/20\}$
T_j = Total Job Time—Minutes
N = Number of Boxes/Units Moved
LI = Number of Line Items
f_t = Distance from Bin Location to Truck
f_p = Distance from Bin Location to Pallet Storage
Solution: Draw line from N Scale to LI Scale. Mark answer on T_{j1} Scale where N to LI Line intersects.
Draw line from LI Scale to $f_t + f_p$ Scale. Mark answer on T_{j2} Scale where LI to $f_t + f_p$ Line intersects.
Sum of $T_{j1} + T_{j2}$ equals the earned minutes for the job.
Example shows calculation for $N = 100$, $LI = 50$, $f_t + f_p = 500$.
$(f_t + f_p)$
Example
Example
Q

FIG. 1

complete the rewarehousing job, all of the ten jobs must be accomplished. Then the standard or allowance for doing the job should be the summation of the elemental times. (The table on page 348 leads to the development of the time formula.)

The occurrence factors of the elements have been developed from the extensive statistical sampling of 4,000 historical rewarehousing projects.

Element Number	Occurrence Factor and Description
1. Pull Item	This occurs once for each item pulled from the shelf.
2. Bag or box material	This occurs once for each item pulled from the shelf.
3. Carry to pallet	Studies show that a warehouseman carries 2 line items at a time to the pallet placed at end of bin row.
4. Carry pallet to truck	An average of 20 line items of bin stock are required to fill one 4'×4' pallet or "egg crate."
5. Obtain flat or safety pallet	A flat pallet or "egg crate" is obtained for each 20 line items picked from the shelf.
6 and 7. Prepare paperwork	A "Kill Location" is performed for each line item rewarehoused.
8. Make cartons	Samples show that a carton is made once for every two line items.
9. Check stock number	Once for every line item.
10. Prepare Form 50B and attach	Once for every line item.
11. Obtain fork lift	Once for every line item.

The time formula is then:

$$T_j = N(.040) + N(.075) + (2).177\,\frac{LI}{2} + .209[.5792 + (.0023)f_t(2)]\,\frac{LI}{20} + [.2758 + (.0023)f_p(2)]\,\frac{LI}{20} + (.739)LI + (.481)LI + (\tfrac{1}{2})(.522)LI + .021LI + .895(LI)$$

which simplifies to:

$$T_j = .209 + .115N + 2.524LI + [.8550 + .0046(f_t + f_p)]\frac{LI}{20}$$

Applying an allowance for personal time, rest and delay the final time formula for bin rewarehousing is:

$$T_j = 1.20\left\{.209 + .115N + 2.524LI + [.8550 + .0046\,(f_t + f_p)]\frac{LI}{20}\right\}$$

The time to place the material in the new location is easily calculated by a similar formula. The time formula is readily adaptable to a nomograph for the foregoing example and shown as Figure 1.

The time formulas are presently being used extensively at OOAMA in allocating manpower to major rewarehousing programs and also for scheduling rewarehousing at periods of slack debit and credit workload.

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Toward a Unified Concept of Job Design

by **ELWOOD S. BUFFA**

Associate Professor of Production Management, University of California, Los Angeles

ARE the data provided by psychologists and physiologists to remain in one set of books and motion study concepts in another? In the post-war period the field variously labeled human engineering, human factors or biotechnology, has generated worthwhile data applicable to job design so fast that it is a major task just to read it. The disturbing part of it is that the Industrial Engineering profession seems to feel that human engineering applies only to high altitude flight. Not so, they are talking about production problems too. The working concept of job design has been restricted basically to motion study and job improvement while in many related fields of psychology and physiology basic research has been going on which demands a re-examination of these concepts and a broadening of our viewpoint. We need to be thinking in terms of original design rather than simply improvement and in terms of a unified concept which embraces the broader view of the organization of tasks into jobs, working environment, the physical and psychological capabilities and restrictions of man as well as principles of flow and arrangement of work. It is the purpose of this paper to examine a broadened unified concept of job design.

THE MEANING OF JOB DESIGN

Job design is concerned with two broad areas: 1. job content and 2. work methods. Given the job content, the work methods design is meant to develop the optimal combination of the remaining variables of the job. Measures of effectiveness in these situations are productivity, quality, errors, worker acceptance, etc., with productivity being regarded as controlling in most industrial situations.

Unfortunately, if we accept a given job content and then try to arrive at some optimal combination of the resulting variables, we run the risk of suboptimization, for job content is also a major determinant of effectiveness. Thus, we may have taken an entire complex assembly process and broken it down into a series of operations so that it could be produced on an assembly line. The line was designed to meet certain capacity-demand requirements, say an output of 480 units per 8-hour shift, or one per minute. This dictates then, the maximum content of each of the operations. They can take no longer than one minute each. What is more, there is a certain required sequence of assembly, so that operation No. 1 takes the elements that come first which require 1 minute or less, operation No. 2 the second 1-minute group, etc. Of course, there is commonly some flexibility possible so that by rearrangement of sequences, we can end up with the job content in each operation which seems to make the most sense in terms of uniformity of skills required, difficulty, balance, etc. Nevertheless, the one minute limit is the great dictator. *But, how would this design compare with other basic alternatives of job content?* We can see that if we were to consider as a part of the problem all possible alternatives of job content, there would be a baffling number. Unfortunately, there is very little information available to guide us and the result in practice is that other considerations commonly dictate job content (10).

GUIDES TO THE DETERMINATION OF JOB CONTENT

Over the years since Adam Smith first recognized its advantages, the main guide to the determination of job content has been *division of labor*. We have accepted this idea almost completely. Unfortunately, however, neither Adam Smith nor anyone following him specified a limit of the principle and it has been applied as a one-way mechanism to achieve the maximum benefits of job design. Jobs have been broken down to the point where the worker finds very little satisfaction in the performance of his tasks. In recent years there has been a reaction to this. The few investigators found that combinations of operations to produce jobs of greater scope recaptured workers' interests, and increases in productivity, quality level, etc. were reported.

The new term, *job enlargement*, was created and applications were written up in the literature which reported glowing results. Unfortunately, however, although job enlargement recognized that division of labor could be carried too far, it could not specify any principles or guides as to how far to go in the other direction. It, too, was a one-way mechanism. People divided into two camps, the divisionists and the enlargers. Adherence to the divisionists' camp sneered that "for 200 years we have reaped the economic benefits of division of labor and now we are supposed to believe that we can continue to make economic progress by simply reversing that trend." The enlargers claimed that division of labor had made the worker a mere link in a giant machine. The possible answer lies in research attempts to isolate the factors that determine an optimal combination of tasks to make up jobs (9) (10) (25). Perhaps additional projects need to be directed toward the determination of the phases of work which best suit man and those which are more appropriate for machines.

The more recent literature tends to stress the job design concept by accepting a broader set of criteria and emphasizing original design rather than improvement

of existing methods (9) (10) (20) (31). Lehrer emphasizes the illusive criterion of job satisfaction relating it to the dominant short run and long run economic criteria (20). Davis, Canter and Hoffman, together with Marks, have attempted to come to grips both philosophically and experimentally with the combined job content—job methods scope of job design (9) (10) (25). Nadler has stressed some of the implications of original design as opposed to the traditional philosophy of improvement (31).

DETERMINANTS OF JOB METHODS

The design of job methods is a field which has received a great deal of attention since the time of Taylor. Over the years a great deal of handbook data have been generated which may be drawn upon to develop method designs which tend to optimize productivity and other measures of effectiveness for a given set of conditions. These handbook data are in the areas of control of the working environment, physiological data of body strength and sizing, psychological data related to the various sensory inputs to the human operator, principles of the arrangement and flow of work and data on fatigue and work schedules. These data are applied within a framework of physical and economic limitations. Physical limitations may relate to existing products, machines, and layouts. Economic limitations refer both to the economic resources of the organization and to the justifiable expenditures on a given project. These justifiable expenditures depend to a great extent on the volume and market stability of the products. Thus, the work methods designed for a high-volume automotive part, such as a spark plug, will justify careful study from all viewpoints, as well as expenditure of funds for machines, jigs, fixtures, and other special tools. On the other hand, job designs to produce a novelty toy, which may cease to exist in six months, might be quite crude. Thus, the job designs are likely to be evolutionary and change with gross changes in the demand for the part or product.

A CONCEPTUAL FRAMEWORK OF JOB DESIGN

As we have already noted, conceptually the design of jobs may be divided into the determination of job content and the determination of methods of execution. In general, job content is most commonly not consciously designed, but is the result of limitations of production quotas, product designs, machine designs, layouts, pacing effects, and the desire to make skill requirements uniform within jobs. Within these limitations, the balance of pressure to gain the advantages of the division of labor on the one hand, and to design jobs that meet worker satisfaction needs through job enlargement on the other hand, determines the scope of jobs, as shown in Figure 1.

Whether an organization leans in the direction of finely divided jobs or enlarged jobs depends upon managerial philosophy, traditions within the industry and within the individual company, and the degree of entrenchment or commitment of investments in existing systems. Job content then becomes an input to the analysis and determination of job methods. Given job content, an optimal method design is a complex consideration of environmental effects, psycho-physiological data, principles of the arrangement and flow of work, and data on fatigue and work schedules all applied within a framework of physical and economic limitations. Figure 1 shows the relationship of these various factors in determining job content and job methods. Job design necessarily considers these various factors as a whole, rather than as independent components of the system. Since all of these various factors have an effect on measures of performance, it is difficult to see how we can continue to ignore the flood of research data which have developed in the last ten years from the source of the physiological and psychological laboratories, and also how we can continue to ignore the need to develop principles which will be effective guides in the determination of job content.

Although real guides to job content are lacking, this author feels that the data, which have been developed mainly by physiologists and psychologists, have not been integrated adequately into current concepts, practices, teaching, and textbooks. Space does not permit an adequate coverage here of the psycho-physiological data available, but let us take time to see the nature of what is already available in order that we may see what we are missing.

THE WORKING ENVIRONMENT

Some people might argue that inclusion of the working environment implies too broad a definition of work methods, but there is adequate evidence to show that environmental factors such as temperature, humidity, noise, lighting, and contaminants can produce marked effects in such measures of effectiveness as productivity, errors, quality levels, and employee acceptance of the job situation as well as measures of physiological wellbeing. Therefore, we cannot measure the effectiveness of a job

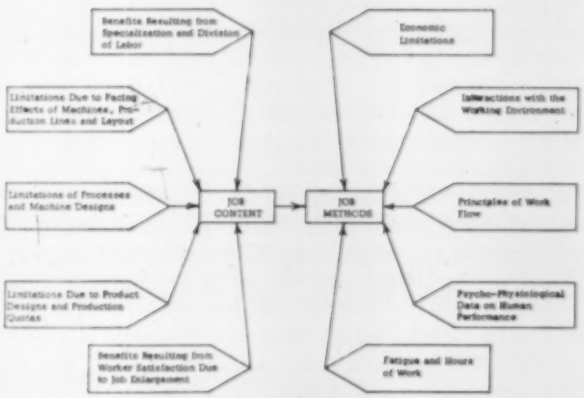
Benefits Resulting from Specialization and Division of Labor
Economic Limitations
Limitations Due to Pacing Effects of Machines, Production Lines and Layout
Interactions with the Working Environment
Limitations of Processes and Machine Designs
JOB CONTENT
JOB METHODS
Principles of Work Flow
Limitations Due to Product Designs and Production Quotas
Psycho-Physiological Data on Human Performance
Benefits Resulting from Worker Satisfaction Due to Job Enlargement
Fatigue and Hours of Work

FIG. 1. Factors Affecting Job Designs.

design without a knowledge of the working environment in which it will be placed. It is a part of the total picture.

To assess the state of the knowledge that we have in this area, let us point out that the environmental indices of temperature, humidity, and air flow have been combined in a single scale called effective temperature. This psychological scale measures the sensation of warmth or cold as affected by all of these factors (40).

Using this scale, the zones of physiological compensation for hard work, moderate work, and light working levels have been determined (40). Mackworth demonstrated a strong relationship between effective temperature and the number of mistakes made when careful clerical detail is important (23). Above about 90 degrees effective temperature, there was an astounding negative effect. For heavy manual work, one study showed that above approximately 80 degrees effective temperature, the foot pounds of work that could be accomplished fell drastically, and at 95 degree effective temperature was less than half of normal levels. Brouha has shown that the physiological cost of doing work under conditions of elevated effective temperature increases drastically and has designed protective clothing in the form of a ventilated suit for extreme exposures (5).

Although no one has ever demonstrated any steady state effect of *noise* on productivity, recent work shows that there is a possibly important health problem (13) (14) (36). These studies indicate that hearing losses in speech frequency ranges are somewhat greater for typical industrial populations than for the general population. However, for occupations such as riveting and generally noisy factory conditions such as glass manufacturing, hearing losses are severe enough to produce deafness. How many Industrial Engineers are aware of the actual noise levels within their plants? Noise isolation, absorption, and other control techniques are fairly well known, and should be used more often than they have been.

Factory *lighting* today seems to be based upon the view that, "If 50 foot candles are good, then 100 foot candles of illumination are better." This is perhaps a result of the fact that general illumination does not cost a great deal and that no one has ever shown that the levels used are injurious. On the other hand, Tinker has shown in a number of controlled experiments that there is a critical level of illumination for a given task and that beyond that level there is practically no increase in performance for increases in intensity (37). This would indicate that increases in intensity beyond these critical levels are of no value. In all of his experiments, Tinker found no case where the critical level of illumination was beyond 50 foot candles. Yet, the most generally used industrial lighting standards show recommended values of 100, 200 and even 300 foot candles (41). Are we wasting resources by ignoring the problem of industrial lighting?

Finally, so far as the environment is concerned, handbook data giving maximum allowable concentrations of every conceivable type of industrial poison are readily available (32). While in many states, laws control the amounts of these contaminants allowed, it does not seem appropriate or within the canon of ethics of Industrial Engineers to react to the problem only when the law demands it.

ANTHROPOMETRIC DATA

One of the areas of physiology which provides basic data for job designers is anthropometry, the measurement of the size of the human body and other characteristics such as physical strength. Data of this nature make it possible to specify work area limits, the height of chairs and work tables and the design of levers and hand wheels so that they do not overtax the physical strength of the bulk of the working population. Ordinarily, this type of data is given so that we know something not only of average values but of the distribution of values. This is very important because we should be thinking of designs that accommodate a large share of the working population rather than some concept of average man. Therefore, with presently available data, if the task required a man to exert a pull with the right hand outstretched, handbook data indicate that 95% of the male population should be able to exert a force of 52 pounds (16). This then, becomes a maximum force which we should expect a man to exert under these conditions and mechanisms to provide the required mechanical advantages would have to be designed. The important thing is that the design specification is taken from man's capabilities rather than the reverse. The resulting job should be one that a large number of people can perform and therefore eliminates the need to seek out industrial freaks, who can perform superhuman tasks. Jobs designed so that required arm forces do not exceed the values of this study, could draw on almost anyone in the male population and expect that their arm strength would be adequate. In addition, anthropometry has measured the physical dimensions of man in almost every way possible to furnish data for seating, table heights, and a multitude of other possible uses in matching work-place designs to human needs. Even in matters as old as work area limits, anthropometry has recently provided data which revise the old standards for normal work areas (35).

SPEED AND ACCURACY OF MOTOR RESPONSES

Psychologists and Industrial Engineers have spent a great deal of effort to determine basic data in this area. As working tools, however, we have been more prone to use motion standard data which have been commercially developed. While the standard data have a place in evaluating gross alternatives of methods design, these systems do not reflect the subtleties of knowledge available

in this area. For example, a great deal of effort has gone into determining the conditions under which positioning elements can best take place (1) (3) (4) (12). Studies of dial settings, cranks, and hand wheels have furnished basic data on optimal diameters, ratios of revolutions of a dial to pointer movement, optimal positions of cranks and hand wheels, etc. (8) (18).

INFORMATION DISPLAYS

In many industrial operations, workers must read dials, meters, receive auditory signals, or determine by sense of touch, which knobs to turn in order to control their processes. Indeed, as we proceed in the direction of automation, business and industrial operations will emphasize these kinds of situations where correct operation depends upon power interpretation of information displayed to one or more of the body sensory mechanisms. This raises the question of how information should be displayed in order that errors and decision time are minimized. Visual displays have probably received the most attention. Questions like these have been raised and partial answers have been provided through controlled experimentation. Which dial shapes are most legible? What scale units should be used and how should they be marked on dials? Do people have number preference patterns that affect their interpretation of dial reading? What characteristics of numbers and letters make them most legible? Are black numbers on a white background superior to white on black? How big should letters and numerals be and what proportions of line thickness, height, and width are best? How should systems of dials be arranged? Experimental work has been carried out on these as well as many other questions in this area (5) (19) (33).

In complex operations where a number of controls are used, coding by color, size, shape, or location helps to distinguish between them so that mistakes are minimized. Hunt found that round knobs could be distinguished from each other when the smaller was 5/6 the size of the larger (17). The location of controls can be used to distinguish them from each other, also. Again, Hunt found that when toggle switches were arranged in vertical columns that the errors in blind reaching to specified switches were lower than when the switches were arranged horizontally in rows (17). For vertical arrangements he found that a five-inch difference in location was desirable but for horizontal arrangements this difference had to be extended to eight inches. Hunt also investigated knob shapes that could be distinguished solely by touch.

FATIGUE AND WORK SCHEDULE

Scheduling the hours of work is a part of job design. For some very heavy industrial jobs a man might work 20 minutes and rest 20 minutes. This was the case for the "shake out" of poured iron castings at the foundry of a well-known automotive company. It was a continuous operation which required the worker to break open the iron molding box containing the hot casting. This was done over a vibrating grate so that the molding sand could drop through to a recirculating conveyer. The casting was then conveyed to subsequent cleaning operations but the worker then placed the cope on one overhead chain conveyer hook and the drag on another. Each half weighed about 50 pounds and the work was done under conditions of high temperature, dust from the molding sand, and high noise intensity. The schedule of 20 minutes of work and 20 minutes of rest was probably none too generous. This type of very heavy work is not too common today but it occurs often enough that there is a continuing interest in the subject of physical fatigue and rest allowances.

Unfortunately, we still lack an accepted framework for the establishment of rest allowances based on rational or scientific measurements. In most instances, schedules of *fatigue allowances* for various types of work are usually based on general acceptability and are often the subject of agreements between labor and management. Recent research has indicated that physiological methods of measurement hold considerable promise for the determination of work loads and optimal environmental design.

One application of physiological methods that goes to the heart of the long-standing question of rest pauses is the recent work of E. A. Müeller in Germany (28). Based upon his studies, Müeller proposes an energy expenditure standard of 4 large calories (KCAL) per minute as being the maximum that a man can expend continuously without rest. This level of energy expenditure he calls the endurance limit. If the task demands more than the endurance limit the man must tap his energy reserve and must finally take a rest pause so that his muscles may recover and the products of fatigue be washed away by the blood. He further relates work time and rest or recovery time by the statement that the average expenditure rate cannot exceed 4 large calories over the work plus resting time if the effects of fatigue are not allowed to accumulate. For example, a task which demanded 6 KCAL per minute while working would require an average of 20 minutes of rest in an hour, or a fatigue allowance of 33⅓ percent of the total work plus resting time. This author is not necessarily recommending these particular standards of energy expenditure and rest time; however, with new heart-rate measuring instruments now becoming available, studies of energy expenditure are becoming possible on a practical basis in the factory. The discouraging point is that studies like Müeller's are not even in the ordinary literature to which an Industrial Engineer would be exposed.

A CONCEPT OF JOB DESIGN

This brief review of the nature of handbook data now

available to Industrial Engineers is only a small part of that available. The important point is that the current, more restricted definition of job design which is taught, written about in our textbooks and practiced in the plant is basically a motion-study concept based upon improvement rather than original design. There are no principles or guides to the determination of job content and practically no literature dealing with the subject. Data on environmental factors are known to some extent but are not ordinarily considered a part of the job design problem by Industrial Engineers. About the only anthropometric data that have filtered into hard-core Industrial Engineering literature are those relating to work areas and to chair and table heights. In order to meet the problems of job design as they exist, we must view the problem in terms of a unified concept which admits the interaction between job content and job methods and utilizes the full spectrum of handbook data now available from human engineering as well as the continued use of the data already developed by many forward looking Industrial Engineers.

Job design will probably always be at least partly art. In drawing on the mass of psycho-physiological data, principles of work flow and arrangement, etc., the job designer creates a design which is partly scientific but depends a great deal on his ingenuity in utilizing the capabilities of man, the machine and mechanical aids as well as his ingenuity in fitting the job in with the overall flow of work. Economic limitations go a long way in determining how good the result looks. For low-volume and/or short-run work, the most economical job design may involve rather crude methods and equipment and use known scientific design data to the minimum. On the other hand, high volumes of standardized items may justify the most careful design of jobs from every viewpoint, usually mechanizing many phases of the tasks and subjecting the remaining man-machine relationships to careful scrutiny so that the results are optimally designed jobs within the knowledge and skill of the job designer.

Finally, job design includes a forecast of output based upon the content and methods. Motion standard data are useful here in estimating output as well as comparing the expected output of alternate designs. To forecast output, however, requires an appraisal of fatigue and fatigue allowances or rest time, as well as allowances for personal time or unavoidable delay factors in the job. Thus, job design is inescapably based upon a complex of art and knowledge from many sources.

REFERENCES

(1) Barnes, R. M., *Motion and Time Study*, Fourth Edition, John Wiley and Sons, Inc., New York, 1958.

(2) Barnes, R. M., Hardaway, H., and Podalsky, O. "Which Pedal is Best?", *Factory Management and Maintenance*, January, 1942, Vol. C, pp. 98-99.

(3) Barnes, R. M., and Mundel, M. E., "A Study of Simultaneous Symmetrical Hand Motions," University of Iowa Studies in Engineering, Bulletin No. 17, 1959.

(4) Briggs, S. J., "A Study of the Design of Work Areas," unpublished Doctoral Dissertation, Purdue University, Lafayette, Indiana, August, 1955.

(5) Brouha, L. A., "Physiological Approach to Problems of Work Measurement," *Proceedings, Ninth Annual Industrial Engineering Institute*, Berkeley-Los Angeles, 1957, pp. 12-21.

(6) Chapanis, A., "Studies of Manual Rotary Positioning Movements: I. The Precision of Setting an Indicator Knob to Various Angular Positions," *Journal of Psychology*, 1951, Vol, 31. pp. 31, 51-64.

(7) Chapanis, A., Garner, W. R., and Morgan, C. C., *Applied Experimental Psychology*, John Wiley and Sons, Inc., New York, 1949.

(8) Davis, L. E., "Human Factors in the Design of Manual Machine Controls," *Mechanical Engineering*, October, 1949, pp. 811-816.

(9) Davis, L. E., "Toward a Theory of Job Design," *The Journal of Industrial Engineering*, Vol. VIII, No. 5, September-October, 1957, pp. 305-309.

(10) Davis, L. E., Canter, R. R., and Hoffman, J., "Current Job Design Criteria," *The Journal of Industrial Engineering*, Vol. VI, No. 2, March-April, 1955, pp. 5-8.

(11) Ellis, B. S., "Speed of Manipulative Performance and the Function of Work Surface Heights," *Journal of Applied Psychology*, 1951, Vol. 35, pp. 289-296.

(12) Fitts, C. M., "A Study of Location Discrimination Ability," in T. M. Fitts (Editor), *Psychological Research on Equipment Design*, Army Air Force Psychology Program, Research Report 19, 1947.

(13) Glorig, A. M. D. and Summerfield, A., "Noise—Is It a Health Problem?", *Journal of the American Medical Association*, Vol. 168, September, 1958.

(14) Grings, W., Summerfield, A., and Glorig, A., "Hearing Loss in Relation to Industrial Noise Exposure," *Industrial Medicine and Surgery*, October, 1957, pp. 451-458.

(15) Guest, R. H., "Job Enlargement—A Revision in Job Design," *Personnel Administration*, Vol. XX, No. 2, March-April, 1957, pp. 9-17.

(16) Hunsiker, P. A., "Arm Strength at Selected Degrees of Elbow Flexion," USAS, Wright Air Development Center, Technical Report 54-548, August, 1955.

(17) Hunt, D. P., "The Coding of Aircraft Controls," USAS, Wright Air Development Center, Technical Report 54-221, August, 1953.

(18) Jenkins, W. L., and Conner, N. B., "Some Design Factors in Making Settings on a Linear Scale," *Journal of Applied Psychology*, 1949, Vol. 33, pp. 395-409.

(19) Karpovich, P. U., *Physiology of Muscular Activity*, Saunders, Philadelphia, 1953.

(20) Lehrer, R. N., "Job Design," *Journal of Industrial Engineering*, Vol. IX, No. 5, September-October, 1958, pp. 439-446.

(21) Lehrer, R. N. *Work Simplification*, Prentice-Hall, Inc., New York, 1957.

(22) Luckiesh, M., and Moss, F. K., "The New Science of Seeing," *Interpreting the Science of Seeing into Lighting Practice*, General Electric Company, Cleveland, Ohio, Vol. I, 1927-1932.

(23) Mackworth, N. H., "Effects of Heat on Wireless Telegraphy Operators' Hearing and Recording Morse Messages," *British Journal of Industrial Medicine*, 1940, Vol. 3, pp. 143-158.

(24) MacLaren, W. P., and Chaney, A. L., "An Evaluation of Some Factors in the Development of Occupational Deafness," *Industrial Medicine*, 1947, Vol. 16, pp. 109-115.

(25) MARKS, A. R. N., "An Investigation of Modifications of Job Design in an Industrial Situation and Their Effects on Some Measures of Economic Productivity," unpublished Ph.D. Dissertation, University of California, Berkeley, 1954.
(26) MAYNARD, H. B., STEGMERTEN, G. J., AND SCHWAB, J. L., *Methods-Time Measurement*, McGraw-Hill Book Company, Inc., New York, 1948.
(27) MCCORMICK, E. J., *Human Engineering*, McGraw-Hill Book Company, Inc., New York, 1957.
(28) MÜELLER, E. A., "The Physiological Basis of Rest Pauses in Heavy Work," *Quarterly Journal of Experimental Physiology*, Vol. 38, No. 4, 1953.
(29) MUNDEL, M. E., *Motion and Time Study*, Second Edition, Prentice-Hall, Inc., New York, 1955.
(30) NADLER, G., *Motion and Time Study*, McGraw-Hill Book Company, Inc., New York, 1955.
(31) NADLER, G., "Work Design: A Philosophy for Applying Work Principles," *Journal of Industrial Engineering*, May-June, 1959, Vol. X, No. 3.
(32) PATTY, F. A., *Industrial Hygiene and Toxicology*.
(33) SLEIGHT, R. B., "The Effect of Instrument Dial Shape on Legibility," *Journal of Applied Psychology*, 1948, Vol. 32, pp. 170-188.
(34) SPECTOR, W. L., Editor, WADC Technical Report 56-273, ASTIA Document No. AD110501, Wright Air Development Center.
(35) SQUIRES, P. C., "The Shape of the Normal Work Area," Navy Department, Bureau of Medicine and Surgery, Medical Research Laboratory, New London, Connecticut, Report 275, July 23, 1956.
(36) SUMMERFIELD, A., GLORIG, A., AND WHEELER, E. E., "Is There a Suitable Industrial Test of Susceptibility to Noise-Induced Hearing Loss?", *Noise Control*, Vol. 4, No. 1, January, 1958.
(37) TINKER, M. A., "Trends in Illumination Standards," *Transactions of the American Academy of Ophthalmology and Otolaryngology*, March-April, 1949, pp. 382-394.
(38) WALKER, C. R., AND GUEST, R. H., *The Man on the Assembly Line*, Harvard University Prese, Cambridge, Massachusetts, 1952.
(39) WARREN, N. D., "Job Simplification versus Job Enlargement," *Journal of Industrial Engineering*, Vol. IX, No. 5, September-October, 1958, pp. 435-438.
(40) *Heating, Ventilating and Air Conditioning Guide*, American Society of Heating and Ventilating Engineers, New York, 1955.
(41) "Industrial Lighting," *American Standard Practice*, Illuminating Engineering Society, New York, 1952.

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Reader Comments

NOTES ON INDUSTRIAL ENGINEERING IN EUROPE, by T. E. Fougner, *Journal of Industrial Engineering*, November-December, 1959.

Mr. Fougner in his interesting article claims that European Industrial Engineering Education is lacking in the newer techniques based on mathematics and that "statistics are not compulsory for any engineers, including the Industrial Engineer." This may be correct for some engineering schools. I have however, a definite feeling that it cannot be correct as a general statement, and as an example I take the Norwegian Institute of Technology. There the following courses are of interest in this connection:

1. A general course in *Mathematics*—400 hours, given during the first two years, is compulsory for all engineering students. In this course 30 hours are devoted to an *Introduction to Probability Theory and Mathematical Statistics.*

2. For students taking the Industrial Engineering option of the Mechanical Engineering Department the following compulsory courses can be mentioned:

a. *Mathematical Statistics*—60 hours.

b. *Production Planning and Control*, basic course—110 hours, including 30 hours *Statistical Quality Control.*

c. *Production Planning and Control*, advanced course—110 hours, including 30 hours *Design of Experiments, Correlation Analysis, Variance Analysis and Statistical Estimation.*

d. *Project work in Industrial Engineering*—300 hours, where the students, divided in small groups, work on special problems. Mathematical methods are extensively used in a number of the projects.

3. In a new course in *Applied Mathematics* starting next year, will be included 30 hours *Numerical Analysis* (Linear Programming, Optimization Problems, Non-Linear Equations). This course will be voluntary and open for all students.

4. For students in the Industrial Engineering option, next year there will be arranged a special course in *Advanced Time-Study Techniques*, 30 hours, where great emphasis will be given to the mathematical aspects.

The given information will show that the first steps in introducing mathematical methods in the Industrial Engineering Education has already been taken. Pushed ahead by the great need for using quantitative methods in solving industrial problems, further developments will follow in the next years.—*Knut Holt, Professor at the Norwegian Institute of Technology.*

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President's Comments

by **ALEX W. RATHE**

President of the American Institute of Industrial Engineers, 1960-61

The Road Ahead

THE new Board of Trustees of the American Institute of Industrial Engineers met for its first session upon the conclusion of the Convention Luncheon in Dallas. It was honored by the presence of Mrs. Frank B. Gilbreth who addressed the members on the significance of Industrial Engineering on a national and international basis. There could not have been a more auspicious start of the work of the current officers than to have the privilege of being greeted by the one figure who towers above any other living person in our field, anywhere in the world.

The activities of the Board were greatly facilitated by the splendid cooperation which the 1959-60 officers, under the leadership of Past President Johnson, extended most generously in the development of plans for the coming twelve months. As our predecessors have elevated AIIE achievements to such a high level, ours is a that much easier task.

A key item on the Board agenda was the deliberation by the Trustees upon a Resolution that would set forth the basic objectives as a guide for all Institute activity in the current year. It was unanimously adopted as follows:

Resolution

WHEREAS the 1960-61 Board of Trustees of the American Institute of Industrial Engineers convenes for its first meeting on May fourteenth, 1960, in Dallas, *be it resolved* . . .

- **• • • THAT we voice our sincere appreciation to the Membership for the confidence expressed to us through our election**
- **• • • THAT we desire to acknowledge the splendid achievements of those who preceded us in national office; to them we are indebted for the opportunity to begin our work on the high plane to which they have lifted AIIE activities**
- **• • • THAT we pledge our very best efforts toward the objective of serving each member individually through a strengthening of all the services which AIIE provides; special attention will be devoted during the year to continued—**
  - **reinforcement of our membership qualifications so that association with an organization with top calibre requirements will be ever more widely recognized as a personal asset**
  - **increase in the availability of means to facilitate individual attention to further professional development**
  - **improvement of AIIE programs—in Conferences, publications, research and all other segments**
  - **closer cooperation with individual practitioners, groups and societies in the fields of Engineering, Science and Management—in general as well as with particular consideration of those with whom we share areas of mutual interest and concern**
  - **dedication to the Gilbreth principle of the never-ending quest for the one best way**
  - **service to our communities and the country as a whole, as an especially fitting recognition of the heritage of Henry L. Gantt in the year which brings the one-hundredth anniversary of the birth of this distinguished pioneer of Industrial Engineering.**

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Since its start twelve years ago, AIIE has been able to score mighty advances every single year. We realize that we shall have to give our level-best to keep up the pace set by those who served the Institute before.

Professional Relations

REPORT OF HONORS FOR ENGINEERS COMMITTEE, ENGINEERS JOINT COUNCIL

The Honors for Engineers Committee is one of the many contacts which AIIE enjoys as a member of the Engineers Joint Council. The Institute holds membership on this committee, as do also the American Society of Civil Engineers; the American Institute of Mining, Metallurgical and Petroleum Engineers; the American Society of Mechanical Engineers; the American Water Works Association; the American Institute of Electrical Engineers; the American Society for Engineering Education; the American Society of Heating, Refrigerating and Air-Conditioning Engineers; the American Institute of Chemical Engineers; and the Society of American Military Engineers.

Last year, 1959, was the first during which AIIE had representation on the Committee, and Mr. Leroy K. Wheelock, the EJC Secretary, cooperated in supplying the background of the Committee, which began its official existence a year or two earlier. Essentially the Committee was an outgrowth of efforts by the engineering profession in general, and ASME in particular, in electing George Westinghouse to the Hall of Fame of Great Americans. This Hall is a Greco-Roman colonnade, a semi-circular, open-air, granite corridor that winds some 630 feet around three buildings of New York University at its University Heights campus. Held in trust for the American people by NYU, the Hall of Fame, founded in 1900 by Dr. Henry Mitchell MacCracken, the University's Chancellor, and built from plans by Stanford White, the edifice enshrines the memory of America's truly great by means of bronze busts and tablets.

A few likenesses to be found here are those of Emerson, Irving, Longfellow, Bryant, Bancroft, Poe, Mark Twain, Whitman, Paine, Mann, Audubon, Agassiz, Reed, Grant, Lee, Marshall, Franklin, Washington, Lincoln, Jefferson, Stuart, Whistler, and Boone. Elections are held quinquennially with outstanding Americans—one hundred fifty of them from such categories as university presidents, historians, professors of literature, scientists, authors, artists, state and federal justices, and high public officials—making the choice of no more than seven from the nominations submitted. (The calibre of the electors is indicated by the fact that Grover Cleveland, Woodrow Wilson, and Theodore Roosevelt were electors.) Election to this honor is not easy, for although it is open to "any American citizen who had made his home in the United States, and who has been dead for twenty-five years or more," Stonewall Jackson was not elected until 1955, while Alexander Graham Bell, Woodrow Wilson, and Theodore Roosevelt were only chosen in 1950.

Clearly, then, the attempt to elect Westinghouse—despite his stature—was not a simple affair, and his bronzes were dedicated in the colonnade one hundred and eleven years after his birth. It is interesting to note that at present (before this year's elections) there is only a single person—James Buchanan Eads (1820-1887), designer of boats and bridges and engineer for the deepening of the Mississippi—in the "engineers, architects" category who is enshrined in the Hall of Fame. This does not mean that there are not other names which engineers may claim. However, Fulton, Morse, Whitney, Howe, Bell, and Wright are listed as "inventors"; and Newcomb, Gibbs, and Henry are "scientists."

This year the names of two more notables known to engineers have received the Committee's attention and were given EJC support: Thayer and Edison. The results of the voting are not yet known; however, if these two candidates are successful, some engineers may be disappointed if they consider the category important. General Sylvanus Thayer was Superintendent at the U. S. Military Academy at West Point, which "for years was the only technical school in America," and his fame as "father of engineering education" rests upon the fact that "all technical institutions founded in the succeeding fifty years were profoundly influenced by the Thayer system." Hence, his category is given as "educator." As for Thomas Alva Edison, it would be difficult to disassociate him from his great inventions, and his category is "inventor."

The reader might ask what the chances are that an Industrial Engineer might be chosen. Aside from all other considerations, the time element is a deterrent. Even if one could include such names as Taylor, Towne, Dodge, Gantt, Gilbreth, Dennison—and maybe even Brandeis—as having had something to do with Industrial Engineering, they have just about cleared the 25 years from date of death prerequisite. Consider also the fact that Thayer's name was first put in nomination about fifteen years before AIIE was established!

In addition to its concern for Westinghouse's election to the Hall of Fame and its present interest in furthering the cause of Thayer and Edison for similar enshrinement, the Committee has considered several other matters in the field of honors.

One of the earliest matters to concern the Committee was the

question as to whether there ought to be an overall award for all engineers. That is, should there be established an award commemorating engineering achievement which might be granted each year? At first sight such an idea might seem worthy of enthusiastic endorsement, for it might not only make known to the public what *the* engineering accomplishment of the year was, but it might also choose *the* engineer of the year. However, on second sight, the practicality of this award may be open to question. It did not take long for the Committee to realize that not only does each society have its own ideas as to *the* accomplishment but there exists in each society a long list of awards and honors. In addition, there are a goodly number of joint awards (e.g., Hoover Medal, John Fritz Medal).

A good part of the Committee's efforts was directed, as early as 1957, toward a compilation of awards available to engineers both in and out of the society structure. Although this list was admittedly incomplete and even though it did not include awards for papers, lectureships, awards within industry, or awards sponsored by foreign societies, it showed about four dozen awards in the "general" field alone. In addition, it showed about an equal number offered by societies holding EJC membership.

The general award category included recognition for work in human relations as well as for accomplishments in both pure and applied technology. At least two of these are known to almost every Industrial Engineer—the Gilbreth Award and the Frederick Winslow Taylor Award, both of which are presented at the annual SAM-ASME conference in the spring. The Gilbreth Medal is awarded by SAM to Americans, without restrictions, for achievement in the field of motion, skill, and fatigue studies, while the Taylor Award, another SAM award, is also granted without restriction but rewards advances in motion and time economy, simplification, and standardization. *Journal* readers might be inawarded intermittently, again with no restriction, for contributions in the field of industrial management; the American Association of Engineers' Clausen Medal for performance of distinguished service for the social and economic welfare of engineers; the James Forrestal Memorial Award, issued by the National Security Industrial Association for cooperative effort between industry and the government and service to national security; and the Washington Award, a bronze tablet issued by the Western Society of Engineers in recognition of service in advancing human progress, to mention but a few. Space will not permit more explicit mention of the many awards for work in physics, communication, illumination, astronomy, control instruments, metals, and many other aspects of pure and applied science. All these, it should be repeated, are in addition to the more than four dozen awards of individual societies holding membership with EJC.

The Committee has also recommended that the United Engineering Trustees consider the establishment of a "Hall of Fame" or some equivalent center for outstanding engineering achievements in the major recognized fields of engineering in the new United Engineering Center. Although this proposal was made to the EJC Board, no formal action was taken, but an informal referral was made to UET.

However, at present the Committee has under consideration a proposal that would recognize outstanding achievements in the recognized engineering fields in yet another way. A detailed memorandum was prepared proposing the establishment of a procedure for the collection and dissemination of a selection of outstanding engineering achievements from the principal engineering societies. It was clearly defined that the selection of outstanding engineering achievements—be it one or more—would be the responsibility of each of the participating societies. No attempt would be made to select a single achievement as being representative of the accomplishment of the entire profession for the entire year, but, rather, every effort ought to be made to disseminate as widely as possible the list selected by the societies, it being the responsibility of the individual society to promote its own selection through its own channels. Of course, a single national list, as compiled by EJC, could be used to emphasize the accomplishment of the profession as a whole.

In these Awards for Excellence of Engineering Achievement there would be no attempt in any way to emphasize the accomplishment of a single individual or a single group. This would remain in the province of the society selecting the accomplishment. Moreover, it was recognized that it might not be easy for a society to come to a final selection of *the* one accomplishment representing the society's activities. Even though it would be proposed that each society keep its selection to a minimum, it would be possible for some forty or more national achievements to be worthy of recognition, for it was proposed that societies other than those having representation on the Committee be invited to select engineering achievements.

Two more matters may be of interest. One concerns a suggestion from the EJC Committee of Secretaries, which took cognizance of a fact, stated above, involving the classification of personages in the Hall of Fame of Great Americans. This committee suggested that perhaps the EJC Committee on Honors for Engineers review the requirements for classification. The second matter concerns the recent Public Law (PL 86-209), which was signed by President Eisenhower and which provided for recognition of individuals making "outstanding contributions in Science and Engineering." The National Science Foundation is to design the medal and the National Academy of Science is to supply recommendations to the President for eligible candidates. The Honors Committee may decide to prepare a slate of outstanding engineers for submission to the National Academy of Science with the voice of EJC behind it. (As usual in such matters, qualifications are quite broad and limited to "living United States Scientists or Engineers" credited with "outstanding contributions in the field of science and engineering to the security of the United States or the progress of mankind.") At the last investigation, it was reliably reported that the proposal has not yet come before the National Academy of Science. Until the authorization is received there, no work can be done on the procedure and methods of recommending engineers for these awards.

These, then, are the matters under discussion by the Committee. However, aside from these considerations, the importance of honors and awards cannot be overlooked. If the objective of a society is to advance the profession, the value of honors and awards lies not only in the recognition of a noteworthy advance and as a reward for efforts expended, but also as a means of informing everyone outside the profession of the accomplishments in an important endeavor. Moreover, this recognition must be in the hands of persons fully conscious of the high task to be performed, for, if it is to have meaning, it cannot be administered by a group of mutual admirers. The EJC Committee on Honors was quite aware of these possibilities, and so, from the very outset, it set forth among the qualities necessary for a program of honors and awards such concepts as *timeliness, specificity, identifiability* and *non-partisanship*.

Wallace Clark was fond of quoting a statement made by Woodrow Wilson that the progress of the world was made by groups of "disinterested" men. Not only does this hold true for progress in a profession, but it is certainly valid if a proper evaluation of achievement is to be made.

Prepared for Professional Relations Committee
By WILLIAM J. JAFFE

Institute Interests

CALENDAR

August 7-13: Eleventh Annual Industrial Research Conference, Arden House, Harriman Campus, Columbia University, New York, N.Y. Write: M. F. Garvey, Secretary, Industrial Research Conference, 409 Engineering Building, Columbia University, New York 27, New York.

August 29-September 3: International Information Theory Meeting, London, England. Write: Dr. Colin Cherry, Department of Electrical Engineers, Imperial College, University of London, Exhibition Road, London S.W. 7, England.

September 12-16: Pan American Congress on Engineering Education, Buenos Aires, Argentina. Write: Gail A. Hathaway, Chairman Committee on International Relations, Engineers Joint Council, 29 West Thirty-Ninth St., New York 18, New York.

September 19-23: Seventh Convention of the Pan American Association of Engineering Societies, Buenos Aires, Argentina. Write: Gail A. Hathaway, Chairman Committee on International Relations, Engineers Joint Council, 29 West Thirty-Ninth St., New York 18, New York.

September 26-30: Instrument-Automation Conference and Exhibit and Fifteenth Annual Meeting, New York Coliseum, New York, New York. Write: William Kushnick, Executive Director, Instrument Society of America, 313 Sixth Avenue, Pittsburgh 22, Pennsylvania.

October 10-11: Operations Research Society of America Eighteenth National Meeting, Statler-Hilton Hotel, Detroit, Michigan. Write: George O'Brien, Touche, Niven, Bailey and Smart, 1292 National Bank Building, Detroit 26, Michigan.

October 10-12: International Systems Meeting, sponsored by the Systems and Procedures Association of America, Hotel Commodore, New York, New York. Write: David Merriman, President, Systems and Procedures Association, 4463 Penobscot Building, Detroit 26, Michigan.

October 20-22: Seventh International Meeting—The Institute of Management Sciences, Hotel Roosevelt, New York City. Write: James Townsend, 30 East 42nd St., New York 17, New York.

November 27-December 2: American Society of Mechanical Engineers Annual Meeting, Statler-Hilton Hotel, New York City. Write: L. S. Dennegar, ASME, 29 West 39th St., New York 18, New York.

December 26-31: One Hundred Twenty-Seventh Annual Meeting, American Association for the Advancement of Science, Philadelphia, Pennsylvania.

PERSONALITIES

ROSS W. HAMMOND

Ross W. Hammond, assistant manager of the Lubbock Chamber of Commerce, has been named vice-president of the American Institute of Industrial Engineers.

Hammond, who recently joined the Chamber of Commerce staff to head the industrial development program, was notified April 22, 1960, of his election to the office in AIIE, a professional society of Industrial Engineers with National Headquarters in Columbus, Ohio. As a vice-president, Hammond will be a chief regional administrator for the organization in the four-state area of Texas, New Mexico, Oklahoma and Kansas.

Formerly area development engineer with Texas Electric Service Company in Fort Worth, Hammond holds a bachelor of science degree in electrical engineering and a master of science degree in Industrial Engineering from the University of Texas. He is past president and past member of the board of directors of the Dallas-Fort Worth Chapter, AIIE; a member of Tau Beta Pi, Eta Kappa Nu (naticnal engineering honor societies), Southern Industrial Development Council, and Operations Research Society of America.

He served in the U. S. Air Force during World War II from 1943 to 1946. He was born in New York City where he attended public schools. He is married to the former Faye Keith of Austin and the couple live at 3105-B 33rd Street, Lubbock, Texas.

COUNCIL FOR INTERNATIONAL PROGRESS IN MANAGEMENT

The American Institute of Industrial Engineers has become a member of the Council for International Progress in Management, it was announced by Colonel Philip Garey, Vice President of Operations of the Council.

The Council, established in 1933, is a non-profit management association that operates entirely at the international level, furthering the spread of modern management principles and practices throughout the world.

Dr. Lillian M. Gilbreth, President of Gilbreth, Inc., will represent the AIIE on the Board of the Council. For close to forty years, Mrs. Gilbreth, a management consultant of world reknown, has carried on the business started by her husband. She is a pioneer of the international management movement and an active lecturer in management both in the United States and abroad.

EIGHTH ANNUAL ENGINEERING MANAGEMENT CONFERENCE

Through the cooperation of seven professional engineering societies the Eighth Annual Engineering Management Conference is being planned for September 15-16, 1960 at the Morrison Hotel in Chicago, Illinois. The subject of the conference will be "Managing Tomorrow." Due to the extremely critical nature of engineering and its management today, both the subject and meeting are important to the future of engineering. It is expected that over 600 people will attend to participate in this important conference.

The conference will be broken into four parts. The morning of the first day will discuss the "Impinging Forces." This will set the stage for the two day conference by identifying the major forces or influences already bearing upon, or beginning to bear upon, 1. the national welfare, 2. private industry, 3. the availability of raw materials, 4. resources and technology with which to meet national and industrial needs, all to be interpreted in the end for the benefit of engineering management at all levels. Economic forces include consideration of both domestic and foreign competition, availability and cost of raw materials and labor here and abroad, the effect of foreign trade alliances such as the European common market, tariffs and other government policies. Can we maintain a high cost economy when the traditional barriers of distance, inadequate foreign technology and

foreign labor costs are rapidly disappearing? How can this nation properly provide for the technological progress it must make if it is to survive? Weapons research may be very successful, but if we do not also provide for technological progress in other areas, we can lose the *economic* struggle.

The second session will discuss "New Requirements and New Aids for Managers." This is designed to bring out new demands on managers in terms of forecasting, planning, scheduling, organizing, integrating and measuring technical work and also major advances in using data processing machines to study alternatives and support managerial judgment.

The third session will discuss "Impact on Professional People." This will bring out the continuing trends towards more brain work and less muscle work by men, more repetitive work by machines and less by men, longer range and more detailed planning, scheduling, integration and measuring required by increasing complexity, inner-related effects and economic impacts of mechanization and automatic machine production.

The final session will discuss the "Impact on Education." This should bring out implications for all engineers who are in or aspire to positions as managers of technical work. This will include the impacts on technical schools, business schools and also on continued postgraduate and home study. In these times of rapid technological change, self education can never cease for one who plans to continue to grow into larger responsibilities.

Also on the program is a luncheon address by Mr. Walker Cisler, President of the Detroit Edison Company and President of the Power Reactor Development Company. In addition, Mr. Peter F. Drucker, Professor of Management, New York University and also author of several books will give the banquet address the evening of September 15.

The seven professional engineering societies sponsoring this Conference are the American Institute of Electrical Engineers, American Institute of Chemical Engineers, American Institute of Industrial Engineers, American Institute of Mining, Metallurgical and Petroleum Engineers, American Society of Civil Engineers, American Society of Mechanical Engineers and the Institute of Radio Engineers.

THE ENGINEERING INDEX

The Annual Edition of *The Engineering Index*—1959—was distributed in June 1960. Advance orders were encouraged because there was a limited edition of this important annual volume.

For over seventy-five years *The Engineering Index* has served the engineering profession. It has been industries' authentic guide to the periodical technical literature. Today it stands unrivalled. Engineers consider it a vital part of their reference equipment. Librarians find it reduces their work of searching; government bureaus and educational institutions use it constantly. Industrial organizations subscribe to it regularly to keep their engineers enlightened concerning progress in their respective fields.

In no better way can the progressive engineer keep in touch with current developments and trends in all branches of engineering activity than through *The Engineering Index*. The annotated reference items published provide a comprehensive digest of the important information on technical, scientific and economic problems as recorded last year in engineering magazines, special bulletins and government reports gathered from all over the world.

This is the kind of information needed to keep in touch with all branches of technical research and current developments in all phases of engineering. This volume contains annotations on over 30,000 articles in 249 "fields of engineering interest." It devotes over 100 pages to the list of authors covered in more than fifteen hundred technical periodicals. It includes a list of these publications of engineering, scientific, and technical societies, engineering and industrial periodicals, and publications of government bureaus, engineering experiment stations, universities, and other research organizations. Not necessarily all articles in these publications are indexed, selection being made on the basis of articles dealing with the art and science of engineering.

The Engineering Index is located in the Engineering Societies Building at 29 West 39th Street, New York 18, N.Y. It is a nonprofit organization which works closely with The Engineering Societies Library.

UNITED ENGINEERING CENTER

Stainless steel and glass will sheath the new $12-million, 20 story curtain wall building rising opposite the United Nations Building between 47th and 48th Street it was announced today. To be occupied by 18 leading American engineering organizations, with a combined membership of 300,000, the United Engineering Center will provide 180,000 sq. ft. of floor space.

In addition to executive offices for engineering societies and joint organizations, the Center will house the world's most complete engineering library, and the Engineering Index, a comprehensive indexing and abstracting service for engineers.

Designed as a basic glass and stainless steel grid system with fixed windows, glass spandrels, and a masonry service core, the United Engineering Center will use 20 to 14 gauge stainless steel, Type 302 for the window frames, mullions and column covers. The lobby and entrances will be masonry, glass, and stainless inside and out.

The structure will be owned and operated by United Engineering Trustees, composed of representatives of the American Society of Civil Engineers; American Institute of Mining, Metallurgical and Petroleum Engineers; The American Society of Mechanical Engineers; Americal Institute of Electrical Engineers; and the American Institute of Chemical Engineers, all of which will be housed in the new structure.

Other occupants will be the American Institute of Consulting

Engineers; American Institute of Industrial Engineers; Society of Women Engineers; American Welding Society; American Society of Heating Refrigerating and Air-Conditioning Engineers; Illuminating Engineering Society; Engineer's Council for Professional Development; Engineers Joint Council; Welding Research Council; Engineering Societies Library; Engineering Index and the Engineering Foundation.

Many of the engineering groups are now housed at the Engineering Societies Building, 29 West 39th Street, built more than 50 years ago. With the growth of the engineering profession and resultant demands for additional space, the present headquarters building has long been outmoded.

Collectively the groups conduct a multimillion dollar publishing operation, and sponsor dozens of meetings and conferences each year to provide engineers and others with up-to-date technical information.

Architects for the new building are Shreve, Lamb & Harmon Associates. Turner Construction Company is the general contractor.

Construction is scheduled to be completed in mid-1961.

CLEVELAND CHAPTER

In the operation of a chapter as large as the Cleveland Chapter of the American Institute of Industrial Engineers, the paper work and record keeping become quite a problem especially when the members do it on their own time or possibly a little on the company's time.

One of the critical areas is the task of keeping an up-to-date record of the members. Through the previous years it was largerly done by hand by the joint effort of the secretary and membership chairman. With the changing of addresses, company affiliations, member status, transfer (in and out), it became a critical area and one exposed to erroneous record keeping.

During the summer of 1959, the Cleveland Chapter conceived the possibility of using IBM punched cards which would be specially designed for AIIE usage, having the standard appearing face with the emblem and block on the back which would have the members name listed and could be used for a pocket card for identification during the meeting. The information to be put on these cards was considered and the following punched in: Name, address, member status, company code, and whether the member is a professional engineer.

With this information it became very simple to sort the master deck to pick up any of the following bits of information: Total members, quantity of professional engineers, full members, affiliates, associates. It became very easy to re-sort the deck alphabetically after a meeting and record how many attended and also, run the deck against envelopes and print the addresses for mailing purposes.

To describe the company code, a complete list of the Cleveland Chapter area corporations was made and listed numerically. This number was punched in the card and at any time it becomes easy to find how many members are in any given company and specifically who they are, which is very useful when obtaining information within the chapter on business affiliations, other members, etc.

Even though the Cleveland Chapter is third largest in the nation, I am sure there are many chapters whose membership is in the range of 100 to 200, who are also facing the paper work task which this chapter had been faced with in the past.

The new system has allowed us to be very universal in obtaining information on a moment's notice and has allowed the officers to have on hand an up-to-date membership listing at all times. A sample of available information is shown as follows:

M. B. Acree	457 Terra Lane	Amherst Ohio	C	7A2		0005
G. J. Adler	3825 E. 123 St.	Cleveland 5, Ohio	C	7A2		0010
G. H. Alberga	16818 Holbrook	Shaker Hts. 20, Ohio	C	7M4	43	0015
G. A. Albert	3350 Dalsford Rd.	Shaker Hts. 20, Ohio	C	7A2		0020
R. E. Bade	41 Ohio St.	Akron, Ohio		7A2		0024
E. H. Bailey	22094 Sandy Lane	Cleveland 26, Ohio	C	7A2		0025
J. E. Bammerlin	4802 Rocky River Dr.	Cleveland 35, Ohio	C	7A2	58	0030
D. L. Barnett	2461 Chestnut Dr.	Westlake, Ohio	C	7A2	14	0035
C. M. Barnhard	1742 Maywood Rd.	Cleveland 21, Ohio	C	7AF4	15	0040

LOUISVILLE CHAPTER

Our March meeting consisted of a panel discussion on the subject of "Human Relations and Industrial Engineering." The common problems encountered by Industrial Engineers in administrating changes were discussed by W. Maxwell of International Harvester Company, Garland Hedgespeth of H. J. Scheirich Company, and J. Straight of American Radiator and Standard Sanitary Corporation. Moderator was J. Copenhefer of Famco, Inc.

The subject under discussion at our April meeting was "Cost Reduction Through Multiple Machine Assignments." Speaker and honored guest on this occasion was William N. Bryant, Vice President in charge of Production, American Saw and Tool Company, and Vice President of the Sixth Region of AIIE. Mr. Bryant was President of the Louisville Chapter, AIIE, when the national convention was held here in 1954.

METROPOLITAN NEW JERSEY CHAPTER

Newark College of Engineering was officially presented a charter establishing a student chapter of AIIE at the college. Presentation was made by Paul Lange, Executive Secretary, AIIE. It was received on behalf of the college and students by Dr. William J. Jaffe, Professor in Management and faculty advisor to the chapter. Daniel Mandel, Metropolitan New Jersey President, extended congratulations to Newark College of Engineering on both the establishment of the student chapter and the 75th Anniversary program in which Metropolitan New Jersey is honored to participate. Professor O. J. Sizelove, Chairman, Department of Management Engineering spoke for the college and was presented with a copy of the National Conference Proceedings. Leroy Gillette, Vice President of Region II, AIIE, was introduced and spoke of the importance of student chapters. Dr. Lillian M. Gilbreth, long a friend and benefactor of the college and the Society, who just returned from Australia and was en route to a conference in Miami, interrupted her plans to be Metropolitan New Jersey's honored guest.

Principal speaker for the occasion was Jerome Barnum, international consultant and lecturer. Mr. Barnum emphasized today's need for research and invention in the problem of behavior and group activities.

METROPOLITAN NEW YORK CHAPTER

Each spring the Metropolitan New York Chapter presents an award to the graduating Industrial Engineering students who are attending school in New York City and whose scholarship and contribution to student activities give outstanding promise of achievement in the Industrial Engineering profession.

The recipients of the David B. Porter Award are Messrs. Eliyahu Roshgold and Andrew Torigian. They are currently students in the Day and Evening Divisions respectively at the College of Engineering of New York University. Mr. James Hiram Thomas received the Walter Rautenstrauch Award and is currently attending Columbia University.

The certificates were presented at the Metropolitan New York Chapter's annual dinner—business meeting Saturday, May 21.

ST. LOUIS CHAPTER

The April meeting of the St. Louis Chapter featured a very full and enjoyable program. It took place at the Anheuser-Busch Brewery, and featured a plant tour, a panel seminar on "Time Study Standards versus Predetermined Standards," a film, and the annual students' night presentation of awards.

Moderator for the panel discussion seminar was Dr. Gerald Nadler of Washington University. Panelists for Time Study Standards were A. J. Slagle of Rawlings Sporting Goods and A. J. Wilhite of Wagner Electric; for Predetermined Standards were W. Kuhn of Fred Medart and James Brauer of P-M Steel Co.

R. O. Schwendinger of Anheuser-Busch was Chairman of the Annual Students' Night Presentation. The two student chapters presented a brief summary of the highlights of their respective Industrial Engineering achievement. The Washington University Chapter president is Dennis L. Kessler; Chapter advisor is Professor K. H. Donovan, Assistant Professor of Industrial Engineering. The president of the Missouri University Chapter is W. R. Fuson, and Chapter advisor is Robert M. Eastman, Professor and Chairman of Industrial Engineering. The climax of the program was the presentation of awards to the outstanding students from each University, based on leadership, scholastic ability, character, and indicated potentials in the Industrial Engineering field.

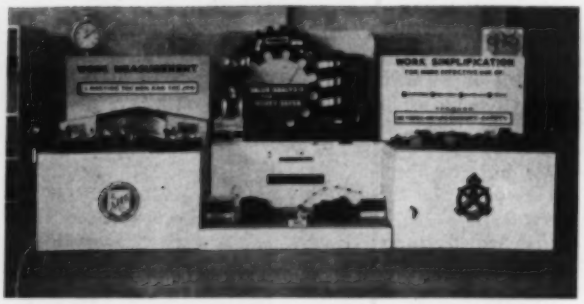
SAVANNAH CHAPTER

Elsewhere in this column can be found a picture of the display sponsored by the Savannah Chapter, AIIE, during National Engineers Week. Members of the Savannah Chapter prepared the display and obtained space for it in one of Savannah's large downtown department store windows.

TOLEDO CHAPTER

The Toledo Chapter, American Institute of Industrial Engineers won first place in the Toledo National Engineers' Week window display competition with a four part animated display prepared by the Industrial Engineering Department of Rossford Ordnance Depot. The AIIE display was judged best of fourteen outstanding displays representing other Toledo Chapters of the leading Technical Societies. The Toledo Chapter's winning entry has been on display in addition to Engineers' Week and at the Engineers' Banquet, the Toledo Public Library for two weeks, the Toledo Chapter's Spring Clinic on March 19 and the lobby of the Rossford Depot at present. It is scheduled for display in the Pentagon Building at Washington and is being offered to the Detroit Chapter for display at the National AIIE convention and conference in 1961. The Theme of National Engineers' Week, "Engineering's Great Challenge—the 1960's," was portrayed in the display through the depiction of advancements in the fields of Work Measurement, Work Simplification, Value Analysis and Vehicular Diagnostic Equipment. Each of these is further described below:

The Work Measurement display, designed by the Ordnance



Supply Systems Field Agency, portrays the steps in applying this management technique and the gains. Low, unequal production requiring excessive supervision characterizes the "Then" practice. A rotating stage illumines four successive phases in implementing work measurement: meeting the men and equipment; developing the standard electronically; reaching agreement on the standard; and applying the standard. The sequence is completed by highlighting the "Now" scene, showing high, equal production with reduced supervision. Intricate timing and drive mechanisms in this display make it symbolic of engineering endeavors.

The theme of the Work Simplification portion of the exhibit prepared by the Ordnance Packaging Agency was Work Simplification. The backboard depicted this theme with the use of four intermittent red lights. Each light conveyed one phase of a job medium. These lights were synchronized with a revolving drum which indicated a breakdown of each phase.

The theme was carried out further with the use of a model automatic packaging line. The conveyor belt was powered and carried the material to be packaged from the breakdown area through a degreaser and preservation and drying tunnel into an automatic packaging machine. The material emerged from the packaging machine in heat sealed bags and entered an automatic cartonizer and sealer and emerged as cartons which then passed through an automatic round steel strapping machine, marking machine, weighing scale and finally palletized through an automatic palletizer.

Value Analysis is a technique utilized, to examine physical items to determine what can be done to reduce the cost of the item, when quantity of expensive item purchases are required, without interfering with the functional or reliable aspects of the item. As portrayed by the display the approach is to redesign or simplify the item or operation to effect: new material, standard parts, ease of assembly, new processes, or less machining.

This is an animated display prepared by the Field Service Division, Tools and Equipment, which gives the effect of a large worm gear driving two spur gears. Lighted windows in the large spur gear show, in turn, the significant steps in value analysis: new material, standard parts, ease of assembly, new processes and less machining. Synchronized with the appearance of each of these steps, is a light which comes on to illuminate the corresponding physical display on the table. Simultaneously, the spur gear appears to drive a "money-belt," which deposits money, saved through the application of value analysis, into a bank. On the smaller spur gear, the phrases "redesign" and "simplify" alternately appear and disappear from sight. On the front of the display, an illuminated traveling endless tape revolves, showing the theme of the entire display, "Automation in Industrial Engineering."

The display, the Development of Chassis Dynamometers and Diagnostic Equipment, also prepared by the Field Service Division, Tools and Equipment, portrays the present method for testing a vehicle and the new concept in diagnostic equipment for all vehicles.

The left side of the display depicts the present chassis dynamometer and its component diagnostic equipment for multi-axis vehicles. With the present method the operator records the data, makes computations and compares the results with standards to determine the faulty areas.

The right side of the display represents the new concept in testing vehicles. In the new concept, the vehicle will be run on the dynamometer and with the use of heat sensitive elements, pressure sensitive elements, light sensitive elements, etc. in conjunction with an electronic computer the operator will read from a television screen exactly what is wrong with the vehicle and what is to be done.

WINSTON-SALEM CHAPTER

The photo shows the exhibit provided by the Winston-Salem Chapter during the local observance of National Engineers' Week. This exhibit was displayed in the show window of a downtown department store. The chapter, a charter member of the local Council of Engineering Societies, also participated in providing films and speakers as program aids for seventeen service and civic organizations. Other exhibits included those prepared by Junior Engineering Clubs, participating engineering societies and manufacturing firms. The attendance of more than four hundred at the annual dinner dance climaxing the week's activities included members of the ten participating societies and distinguished guests active in engineering, education, industry and government.

The Southeastern Regional Conference and Tenth Annual Motion and Time Study Conference for this year replaced the annual Motion and Time Study Conference which is normally co-sponsored by the Winston-Salem Chapter AIIE and Greensboro Area Chapter SAM. Membership registration privileges were extended to all AIIE members and they lent strong support to the March 16-18, Conference held at Hotel Robert E. Lee, Winston-Salem.

Hal G. Worley, a charter member and past president of the Winston-Salem chapter, was elected national vice president of AIIE to represent Region III. Hal is assistant superintendent of wage practices at the Western Electric Company's North Carolina Works.

The Winston-Salem Chapter is proud to have had five of its members appointed as delegates for Region III. Congratulations to Milton Sweatman, Andrew Davis, Ed Collins, Herman Cook and Walter Abbe.

Major Dale S. Jeffers, Chief, Accessories Division, Directorate of Logistic Support Management, Warner Robins Air Matériel Area, Robins Air Force Base, Ga., addressed the regular April meeting of the chapter on "Brain Power."

The following were elected as officers and directors of this chapter at its April business meeting: President—R. A. Lynch; Vice President—M. R. Sweatman; Secretary—W. L. Dudley, Jr.; Treasurer—E. L. Brady, Jr.; Directors—D. T. Watts and Walter Abbe, III.

YOUNGSTOWN CHAPTER

Our April meeting was the Fourth Annual Spring Conference with the theme of "Cost Reduction Through Materials Handling." The Victoria Restaurant and Lounge in Youngstown was the site of the conference. Some of the speakers and their subjects were: J. R. Hensly, Division Industrial Engineer in charge of Methods and Materials Handling for Youngstown Sheet & Tube Co., who spoke on "Proper Materials Handling Methods for Given Plant Situations"; F. C. Wier, Retired Superintendent of Materials Handling for Timkin Roller Bearing Co., Canton, Ohio, who discussed "Men and Machines in Materials Handling"; and the dinner speaker, Mr. H. H. Hall, Co-author of AMHS-ASME Handbook and General Chairman of the American Standards Association in charge of containerization, whose subject was "Containerization."

Our May meeting took the form of a dinner-dance, which was greatly enjoyed by all who attended. Immediately following dinner, officers for the new year were installed. Guest speaker for the evening was Mr. Ed Paulie who is supervisor of management training at the Imperial Works in Oil City, Pennsylvania, and a leading instructor in the famous Dale Carnegie courses. The evening was such a success that we hope to make the dinner-dance an annual event in the Youngstown Chapter.

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Recent Readables

NEW PUBLICATIONS

Papers from the 1960 Nuclear Congress. Copies of the 62 papers presented during the 1960 Nuclear Congress are available. Titles of the various papers may be obtained from: The 1960 Nuclear Congress, 29 West 39th Street, New York 18, New York.

The price is 50¢ per paper or $20.00 for the entire set.

The first objective of the Congress was to provide for exchange of knowledge in the subject area between engineers and scientists and the industry which is dependent upon such information.

AUTOMATION

"Automation Aims at Managers," G. J. McManus, IRON AGE, *page 28, February 25, 1960.*

Companies are now using electronic computers to run individual machines and over-all plant operations. Few production workers are affected. The aim is to speed the work of managers.

"Process Dynamics Prelude-Computer Control Today," CHEMICAL PROCESSING, *page 23, April, 1960.*

Improved payout is often byproduct in considering ways in which control mathematics may be utilized. These are the major products:

1. More comprehensive computation.
2. Continuous computation.
3. Faster computation.

"What Can Numerical Controls Do?" R. H. Eshelman, IRON AGE, *page 149, April, 1960.*

Few ideas have caught the metal working industry's fancy as has control. It is hailed as the answer to many problems. Yet, a fog of terminology still veils it. Here are the types and the jobs they will do.

COST CONTROL

"Equipment Reliability vs. Cost," I. J. Karassik, CHEMICAL ENGINEERING, *page 210, November 16, 1959.*

This is the second article covering the cost concept of equipment reliability. The infant mortality of pumps is discussed as a function of the Reliability and First Cost. The concept of increased long-range costs versus a low first cost is included here.

GENERAL

"Make Record-Keeping Painless," T. W. Hudson, CHEMICAL ENGINEERING, *page 134, January 11, 1960.*

The fact that most operational and maintenance records do not show complete and accurate repair histories is discussed and Union Carbide's system of maintaining an efficient record of price of equipment is illustrated. This system functions from "Cradle to the Grave" and is very flexible.

"The Beginning of Modern Scientific Management," Leslie H. Matthies, OFFICE, *page 112, April, 1960.*

A review of the career of the Father of Scientific Management—Fredrich W. Taylor.

"The Meaning of Management as a Profession," Robert G. Murdick, ADVANCED MANAGEMENT, *page 11, April, 1960.*

Current trends toward professionalization of management are reviewed by a critic who asks for careful definition of terms, and paints an imaginary but striking picture of the day when the licensed manager may become a reality.

"Performance Review and Management," Ernest C. Miller, ADVANCED MANAGEMENT, *page 26, March, 1960.*

The importance of performance review as a communication tool is highlighted by the author of this article, who also stressed the value of integrating the performance review process with already-existing management responsibilities.

"Do Professional Employees Require Special Handling?" IRON AGE, *page 61, March 17, 1960.*

It may be time for management to take a look at the way it handles its engineers and scientists. They have different motives and goals than they had in the past.

"Looking Toward a Theory of Industrial Management," W. V. Owen, ADVANCED MANAGEMENT, *page 13, March, 1960.*

Eight factors representing the basic fundamental aspects of modern industrial management are combined into a theory which in time may result in formation of a "law" governing behavior and health of management as an institution.

"The Development of 'Middle Management' Executives," James M. Henks, ADVANCED MANAGEMENT, *page 23, March, 1960.*

The probabilities of the middle manager making the right moves at the right time can be increased not through a crash program, but by in-plant activity designed to put responsibility for development on middle managers themselves.

"Materials Management Concept Stirs Purchasing Agents Debate," G. J. McManus, IRON AGE, *page 65, March 3, 1960.*

Should all flow of purchased materials be centralized in a single purchasing authority? It's the hottest procurement subject since value analysis arrived.

"Labor States Its Case," Comments by J. R. Hoffa, J. B. Carey, A. F. Hartung, G. L. Brown, G. M. Freeman, J. J. Mara, A. J. Hayes; edited by G. C. Thomas, MODERN MATERIALS HANDLING, *page 97, March, 1960.*

This article contains the exclusive statements from the international presidents of seven labor unions, reacting to the issues raised in this series of articles on labor and mechanization.

This is organized labor telling, in its own words, where it stands. The statements have been edited only to eliminate repetition.

It is labor's answer to the question raised in Part I of the series: "Is There A Labor Threat to Further Handling Mechanization?" The seven men are unanimous in their opinion that automation should not be resisted, but that labor should share in the savings and that results of automation should be subject to collective bargaining.

"Simple Estimates for Complex Work Loads," R. H. Hillsley and A. L. Harlenry, HARVARD BUSINESS REVIEW, *pages 87-96, January-February, 1960.*

A discussion of how to gain the best possible picture of the future workload and its implications for costs and scheduling.

MATERIALS HANDLING

"Using Computers in Parts Distribution," Charles F. Clayton, MODERN MATERIALS HANDLING, *page 114, March, 1960.*

By installing a computer and using it effectively, Factory Motor Parts, Inc. was able to achieve both the often conflicting goals of improved customer service and economy of operation.

Specifically, they were able to cut order processing time 50%, inventory by 25% and paperwork by 80%.

QUALITY CONTROL

"Let's Put Some Sense into Machine Tolerances," IRON AGE, *page 115, December 17, 1959.*

Through statistics—how many times out of 100 or even 1,000 tries will the parts produced by a machine come out to specifications? You must know these "odds" to succeed in this age of close tolerances. A reliable method to control machine accuracy lies in the field of statistical studies.

"Quality Control in the Automatic Factory," A. B. Bishop, INDUSTRIAL QUALITY CONTROL, *pages 5-12, March, 1960.*

Recent and projected advances in graduation technology are examined in an effort to evaluate the role that quality control is to play in the factory of the future.

WORK MEASUREMENT

"How to Determine the Total Sample Size for Work Sampling Studies," John A. Ritchey, OFFICE, *page 79, April, 1960.*

The author believes that misleading techniques are commonly used to figure the size of the sample. He reviews three methods and picks out the pitfalls of each.

"Maintenance Incentives Do Work," FACTORY, *page 226, March, 1960.*

In an exclusive interview with DeLaval Steam Turbine Company plant management, Factory learns how the company decreased its maintenance cost by $150,000 a year while maintenance men increased their earnings by an average of 15%.

"Short Schedules Stretch Output of Maintenance Men," FACTORY, *page 91, April, 1960.*

Can you optimize the size of your maintenance force? It's been done at Wallace and Tiernan. The secret: a new kind of job scheduling that anybody can do. Called Short Interval Scheduling (SIS) the new technique is saving money for Wallace and Tiernan every day.

"Plan to Cut Indirect Costs," FACTORY, *page 100, April, 1960.*

Measurement of indirect work has helped the Maytag Company cut some indirect labor costs by as much as 50%. Management Daywork Analysis (MDA) is the key. It's an approximate measure of non-repetitive indirect work that isn't ready for the type of measurement required for incentive pay.

OPERATIONS RESEARCH

"Putting Linear Programming to Work," J. E. Chenevey, OIL AND GAS JOURNAL, *page 113, March 7, 1960.*

The first of three articles in which the author explains useful tool in nonmathematical terms. Part I is a general introduction.

BOOKS

PIONEERING IN INDUSTRIAL RESEARCH: THE STORY OF THE GENERAL ELECTRIC RESEARCH LABORATORY, *by Kendall Birr, Public Affairs Press, Washington, D.C., 1957, 204 pages, $4.50.*

THE THEORY OF THE GROWTH OF THE FIRM, *by Edith T. Penrose, John Wiley and Sons, Inc., New York, 1960, 272 pages, $6.00.*

ENGINEERING ECONOMY, Third Edition, *by E. Paul De Garmo, The Macmillan Company, New York, 1960, 580 pages, $8.75.*

CEMENTED CARBIDES, *by Paul Schwarzkopf and Richard Kieffer, The Macmillan Company, New York, 1960, 349 pages, $15.00.*

PRINCIPLES OF ENGINEERING ECONOMY, Fourth Edition, *by Eugene L. Grant and W. Grant Ireson, Ronald Press Company, New York, 1960, 574 pages, $8.00.*

INDUSTRIAL PACKAGING, *by Friedman and Kipnees, John Wiley and Sons, New York, 1960, 536 pages, $11.50.*

ORGANIZING FOR INTERNATIONAL OPERATIONS, *by Alexander O. Stanley, American Management Association, Inc., New York, 318 pages, $12.00.*

CYBERNETICS AND MANAGEMENT, *by Stafford Beer, John Wiley and Sons, Inc., New York, 1960, 214 pages, $4.50.*

AUTOMATIC DATA-PROCESSING SYSTEMS PRINCIPLES AND PROCEDURES, *by Robert H. Gregory and Richard L. Van Horn, Wadsworth Publishing Company, San Francisco, 1960, 705 pages.*

ELECTRONIC COMPUTERS: PRINCIPLES AND APPLICATIONS, Second Edition, *by T. E. Ivall, Philosophical Library, New York, 1960, 260 pages, $15.00.*

SAMPLING IN A NUTSHELL, *by M. J. Slonim, Simon and Schuster, New York, 1960, 145 pages, $3.50.*

AN INTRODUCTION TO LONGITUDINAL STATISTICAL ANALYSIS, *by Nathan Goldfarb, The Free Press of Glencoe, Illinois, April, 1960, 220 pages, $5.00.*

MOTION AND TIME STUDY: PRINCIPLES AND PRACTICES, Third Edition, *by Marvin E. Mundel, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1960, $11.95.*

WORK IMPROVEMENT, *by Guy C. Close, Jr., John Wiley and Sons, Inc., New York, 1960, 388 pages, $7.75.*

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SERVICES PROVIDED

Current job openings are published in condensed form in each issue. In addition, a monthly I. E. Opportunities Bulletin is supplied to over one hundred chapters located throughout the U.S.

Each job opening is assigned a **"P"** number for identification. The name and address of the person to contact for additional information concerning a specific job opening is sent to members on request.

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Employers having openings for qualified Industrial Engineers are invited to list them. Government agencies and educational institutions as well as business and industry are urged to take advantage of this free service.

To list your job openings with the Opportunities Service, send all or part of the following information with the name of your contact man to the address below: Type of industry, location, job classifications, minimum educational and experience qualifications, and salary range.

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The following list shows job openings available just prior to press time. If you would like more information about one or more of the positions listed, mail the **"P"** numbers with your name and address to the Opportunities Service at the address below. The Service will advise you by return mail of the name and address of the person to contact for further information, or advise you if the position is no longer available. Your name will not be forwarded to the company with the job opening.

For more current listings, contact your local Chapter Secretary or Opportunities Chairman for the latest monthly Bulletin.

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Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		Remarks
						Years of exp.	Age range	
41	Consulting	Ohio	×	10, 21, 31		5–7		
167	Weapons Systems	Wash. D.C.		50				Ph.D.
213	Air Force	Calif.		15, 32, 42, 43, 44, 53	7.5–	2+	21–	Repair & Modification
273	Air Force	Utah		11, 13, 18, 42, 43, 44, 53	6.3– 7.5	2–		I.E. Degree
279	Air Line	Ill., Colo., Calif.		11, 13, 18, 41–43, 50–52, 70	6.0–10.0	1–6		
423	Air Force	Ohio		Broad	8.8			I.E. Degree
424	Air Force	Ohio		Broad	4.5– 7.5			I.E. Degree
449	Electronics	Mass.		30, 50, 70	6.0– 8.0	1–5		
464	Consulting	N.J.	×	10, 20, 32–34, 42, 43, 54, 71–73, 92	8.0–12.0	5–	30–36	I.E. Degree
465	Consulting	Mass.	×	Senior Engineer	12.0–15.0	10–15	32–50	I.E. Degree or Equiv.
470	Mining & Smelt.	N.M.		11, 13, 26, 36, 42, 45	5.0–7.0		–45	I.E. Degree Preferred
472	Plastic Prod.	Va.		11	8.0– 8.5	1–2	–30	MTM Experience(Woodwkg.)
473	Electronics	Iowa		19, 30, 40, 50	6.0–10.0	0–10		B.S. or M.S. Degree
479	Brass Products	Conn.		10, 20, 36		1–5		Math. Experience
491	Airline	Ill., Colo., Calif.	15%	11, 13, 18, 51, 70	6.0–10.0	1–5	–40	I.E. Degree Pref.
493	Plumbing Supplies	Ohio		11, 13, 18	7.5– 9.0	7–	30–35	I.E. Degree
494	Electronics	Utah		10–18, 34, 36, 40–46, 91	7.5– 9.0	5–10	30–40	I.E. Degree
499	Electronic Equip.	N.Y.		10, 36	Open	3–		I.E. Degree or Equiv.
503	Electronics	D.C.		30	9.0–11.7	5–		I.E. Degree
506	Railroad	Pa.		11, 13, 31, 36, 42, 43	5.7– 7.2	0–2	24–30	I.E. or I.M. Pref.
507	Railroad	Pa.		31–38, 51–53	7.2– 9.6	2–5	24–35	I.E. or I.M. Pref.
514	Air Force	Ohio	25%	12, 17, 18	8.8–10.0	4+		B.S.I.E. or M.S.I.E.
515	Air Force	Ohio	25%	40	8.8–10.0	4+		B.S.I.E. or M.S.I.E.
516	Air Force	Ohio	25%	32, 37	8.8–10.0	4+		B.S.I.E. or M.S.I.E.
517	Air Force	Ohio	25%	10, 13, 16	8.8–10.0	4+		B.S.I.E. or M.S.I.E.
518	Air Force	Ohio	25%	Broad I.E.	8.8–10.0	4+		B.S.I.E. or M.S.I.E.
519	Automotive Parts	Mich.		10, 11, 13, 19, 26, 36, 38, 42	6.0– 9.0	7–20	30–45	College Degree
522	Ind. Fastenings	Ill.		11, 14, 15, 19, 36, 38, 43, 45, 71	6.0– 7.8	1–3	–35	
524	Utilities	D.C.		10, 13, 17, 37	6.0– 7.0	2–3	28–	I.E. Degree
534	Glass	N.Y.	½	11, 42, 43, 44, 45, 46, 47	7.0–	5–	30–40	I.E. or M.E. Degree
538	Papermaking	Pa.		50, 51, 52, 53, 55	open	2–5	25–35	M.S.I.E.
539	U. S. Army	Ill.	×	37, 52, 54	8.8– 9.5	3–		B.S. Degree
541	Communications Mfg.	N.Y.		13, 43, 81	7.0–10.0	3–10	30–40	I.E. Degree or Equiv.
542	Electronics	N.Y.		19, 42, 43	5.2– 8.5	0–3		B.S.—I.E., I.M., or M.E.
543	Air Force (Maint.)	Pa.		11, 13, 18, 44, 53, 91	7.5	4–	25–40	I.E. Degree
545	Consulting	Pa.	×	10, 20, 30, 40, 50, 70, 90	8.0–12.0	5–	28–40	M.E. or I.E.
546	Consulting	Ill.	½	Broad	8.0–12.0	5–	28–40	
552	Smelt. & Titanium	Canada			7.0– 8.5	5–10		
553	Sugar Refining	Md., La.		11, 36, 38, 43	6.2–9.0	0–5		I.E. Degree
555	Office Machy.	Mich.		11, 30–37	9.6–	3–	30–40	Exp. in System Analysis
556	Office Machy.	Mich.		30	9.6–	3–5		Exp. in Quality Control
561	Navy	S.C.		11, 15, 17, 18, 52, 71, 90	7.5– 8.2	2+		Degree
563	Needles	Mo.		92	9.0–10.0	8–10	30–	College Graduate
564	Education	N.D.		30, 40, 50	7.5–	8–	40–50	M.S./Ph.D. or P.E.
566	Education	Mo.		10, 30, 40, 50	Open			College Degree
567	Lumbering Mfg.-Cut Parts	La.		10, 30, 32, 33, 40, 48, 94	4.5– 6.5		25–40	
569	Transportation *(See Below)			10, 30, 42, 43, 47	8.4– 9.6	7–	30–	I.E. Degree
570	Transportation *(See Below)			10, 30, 42, 43, 47	7.0– 8.4	4–	20–	I.E. Degree
571	Transportation *(See Below)			10, 30, 42, 43, 47	6.0–	None	20–	I.E. Degree
572	Mgmt. Consultant	U.S.A. & Europe	×	10, 11, 13–18, 21, 22, 91 or 92	Open	5–	30–40	MTM Experience
574	Aircraft Parts—(Mach.)	N.J.		10, 11, 13–16, 18, 36, 91	9.0–12.0	8–12	32–45	Engineering Degree
578	Education	Ohio		50–54			Open	M.S./Ph.D.—M.E., I.E., or Applied Math.
579	Pharmaceutical	Ill.		10, 11, 13, 14		3–5		I.E. Degree or Equiv.
580	Solid Propellants	Tex.		11, 12, 19, 32, 34, 41–43, 53	7.0–10.3	0–4	25–35	B.S. in I.E. or M.E. Pref.
581	Paper	Ga.		11, 13, 21, 42 (91 or 92 Exp.)	12.0–15.0	3–	35–48	M.S.I.E. Pref.,
582	Paper	Ga.		43	7.5– 8.5		30–40	B.S. in I.E. or I.M.
583	Plastic Molding	Mass.		11, 13–16, 18, 22, 42	7.2–			I.E. Degree
584	Chemical	Pa., W.Va.		11, 18, 38, 52	7.0–	3–	28–	B.S. Degree

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
585	Garment Mfg.	N.J.		10	5.2– 5.7	0–2		I.E. Degree
586	Glass Containers	Ind.		10, 11, 13, 14, 16, 21, 31, 36	6.3– 7.5	2–5	22–35	I.E. Degree Ref.
587	Naval Avionics	Ind.		11, 30, 40, 70	6.2– 7.5	2–4		I.E. Degree
588	Printing	Ohio		10, 20, 30, 40, 42, 43	Open	2–7	–30	I.E. or M.E. Degree
593	Metal Working	Mich.		10, 11, 13, 20, 39, 42	10.0–	10–		Engineering Degree
594	Chemical Mfg.	Tex.		11, 30, 32, 34, 43	7.0– 9.5	2–6	27–40	B.S.I.E.
595	Plastics	Ill.		11, 42–46	7.2– 8.4	5–		B.S.M.E. or B.S.I.E.
596	Mining & Refining	Ariz.		11–13, 18, 26, 28, 35, 36, 38, 48	6.5– 9.0		–40	
597	Needle-Plastics	Dela.		11, 14, 15, 19, 22, 26, 42, 48, 91	7.9– 9.5	4–	28–35	B.S.I.E. or B.S.M.E.
598	Needle-Plastics	Dela.		31, 33, 35, 36, 43, 71, 73, 91	7.9– 9.5	4–	28–35	B.S.I.E. or B.S.M.E.
600	Rubber	Pa.		11, 13, 16, 21, 36	6.0– 7.2	3–5	28–45	
601	Wood and Plastics	Va.		21	7.5– 8.0	2–3	25–35	B.S. Degree
603	Training	Mich.		30—in Metal Cutting	7.0–	3–5	25–50	B.S., M.S., Ph.D. I.E., M.E.
604	Training	Mich.		30—in Plastics	7.0–	3–5	25–50	Same as above
607	Elect. Controls	Mass.		30,32,39	10.0–12.0	5–10	–40	I.E. or M.E. Degree
608	Elect. Controls	Mass.		Production Engineer	6.5– 8.5	2–3	25–35	I.E. Deg. with Electronic or Prec. Mech. Assy. Exp.
609	Research & Devel.	Md.		30, 40, 42		8–		B.S.I.E.
610	Research & Devel.	Md.		30		5–		B.S.I.E.
611	Research & Devel.	Md.		30		3–		B.S.I.E.
615	Heat Trans. Equip. Mfg.	Wis.		11, 14, 15, 19, 32, 38	6.6–	3–	–35	B.S.I.E. Pref.
617	Steel Goods Mfg.	N.M.		11, 31, 35, 54, 70	6.0– 8.0	3–5		I.E. Degree
618	Metalworking	Ohio		10, 11, 19, 32	Open	8		B.S.I.E.
619	Metal Casting & Machy.	Minn.		10, 30, 40, 44, 92	9.0–12.0	8–		
620	Food Machy. Mfg.	Iowa		36, 42, 43	6.0– 8.0	5–		M.E. Deg. or 2–3 Yrs. Col.
621	Boats	Mich.		30, 40	6.0– 8.4			
622	Casing Testers	Texas		30, 71		3–5	–35	B.S.I.E.
623	Semiconductors	Mass.		11, 13, 16, 19, 42	8.0–11.0	3–5		
624	Navy	D.C.		44, 49, 54, 70	4.5– 7.5		Open	
626	Mining, Milling, Smelting	Utah		92, 13, 21	7.9–10.7	5–		Engineering Degree
627	Railroad	Md.		11, 35, 36, 38, 54, 70–73	6.5–10.0	3–	25–	College Graduate
628	Paper & Pulp Mfg.	Maine		11, 18, 22, 43, 91	8.0– 9.0	5–	–40	I.E. Degree
629	Electronics			50–55				I.E. or Bus. Ad. Grad. Major in Math.
630	Textile & Paper Prod.	Tenn.		10, 11, 13–15, 18, 19, 21, 22, 26, 36	6.0– 7.5	2–3		I.E. Degree or Equiv.
631	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47, 90	7.5	3	20–	B.S. in Engineering
632	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	7.5	3	20–	B.S. in Engineering
633	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	6.2	2	20–	B.S. in Engineering
634	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	4.9	0	20–	B.S. in Engineering
635	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	5.8	1	20–	B.S. in Engineering
636	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	6.2	2	20–	B.S. in Engineering
637	Glass	N.Y.		11, 13, 18, 21, 26, 31, 36, 42, 43	9.0–10.0	5–10		
639	Education	N.Y.		10, 30, 40, 50, 60	9.0–12.0	5–15		Ph.D. in I.E.
640	Athletic Equip.	Ohio		11, 13, 16, 19, 26, 32–34, 42, 44	8.4–	5–6	30–40	MTM required
641	Athletic Equip.	Ohio		11, 13, 16, 32, 42	6.5–	3–4	25–45	MTM required
642	Rubber (Ind. Prod.)	Mass.		10, 11, 13–15, 20–22, 32, 36, 38, 43, 42	Open	3–7	25–40	College Graduate
643	Pharmaceutical	Ind.		10, 11, 13–15, 18, 19, 42, 43, 53	5.7– 6.5	0–3		I.E. or M.E.
644	Electronics	Dela.		11, 18, 30–38, 42	Open		Open	I.E. with some M.E.
645	Management Cons.	Minn.		13, 31, 37, 43, 53, 55, 71, 72, 91	11.0–	5–	29–45	Engineering Degree
646	Steel Mfg. & Fabr.	Ala.		30	Open	5–	28–45	Exp. in Steel Fabr.
647	Printing	Eastern U.S.		30	Open		30–45	B.S. in I.E. or Equiv.
648	Chemical	Ill.		91	7.5– 8.0	4–5	25–30	
650	Chemical Proc.	W. Va.		15, 17, 48, 91	6.0– 7.2	0–2		B.S.I.E.
651	Propane Equip.	Ill.		10	5.4– 6.0	3–		Degree not required
652	Oil-Consulting	Middle East		10, 20, 30, 40, 70, 90	13.0–25.0	7–15	30–45	Degree
653	Research Lab.	Md.		30, 40 (Principal Engineer)		3–		B.S.I.E.
654	Research Lab.	Md.		30, 43 (Methods Analyst)		3–		B.S.I.E. or I.M.
655	Film	N.C.		10, 20, 30, 42, 43, 49, 53, 70, 73, 81	Open	0–5	21–30	I.E. Degree
656	Forgings, Stampings, etc.	Northeast		(Division Manager)	15.0–18.0	8–10	35–	I.E. Degree
657	Shirt Mfg.	Colo.		71, 90, 95	8.0–	8–	30–45	Shirt Mfg. & Records Exp.
658	Food Proc.	Minn.	Ltd.	10, 20, 30, 40, 81	5.2– 6.0	0–2	Open	I.E. or I.M. Degree
659	Machine Tool	Ohio		18,32	9.0–	10–	35–	M.E. or I.E. Degree
660	Consulting	N.Y.	×	10, 21, 36, 38, 91, 92	12.0–20.0	8–	35–45	M.E. or I.E. Degree
661	Research & Devel.	Ohio		50, 55, 70, 72	8.0–10.0	3–5	–35	M.B.A. or Equiv.
662	Papermaking	Pa.		Broad Experience	6.5– 8.0	0–3	21–30	I.E. Degree Pref.
663	Automotive	Pa.		31, 36, 38, 45, 53, 54, 71	6.7– 9.7	3–7	24–40	B.S. or B.A. Pref.
664	Automotive	Pa.		11, 14, 15, 18, 19, 22, 36, 45, 91	7.5– 9.7	4–12	23–45	B.S.I.E. Pref.
665	Automotive	Pa.		11, 14, 15, 18, 19, 22, 34, 36, 45	6.0– 7.9	1–6	23–31	B.S. or B.A. Pref.
666	Automotive	Pa.		11, 14, 15, 18, 19, 34, 36	5.5– 7.0	2–15	23–40	Degree not necessary
667	Soft Goods	Midwest		Manager of Mfg. Engineering	18.0–25.0		35–45	I.E. Degree—MTM exp.
668	Pharmaceutical	Ill.		40, 42, 44		0–5	–40	B.S. in Engineering
669	Minning & Refining	Ariz.		11–13, 18, 26, 28, 35, 36, 38, 48	6.5– 9.0		–40	
670	Garment Mfg.	N.J.		54, 71	Open	0–3		B.S.I.E.
671	Chemical	N.Y.		11, 32, 42 (Chief I.E.)	10.0			B.S.I.E.
672	Electronic	N.Y.		10, 30, 42, 43	–12.0	5–		M.S. or B.S. in I.E.
673	Electronic	N.Y.		11, 13, 36	–10.0	2–		Electronic Exp.
674	Chemical Processing	Va.		10, 11, 14, 26, 43	Open	3–5	Open	
675	Power Farm Machinery	Iowa		General	Open	2–5	30–45	I.E. Degree
676	Clay Products	Tex.	Ltd	12, 21, 36, 42, 43	5.8– 6.6	5–	28–35	I.E. Degree or Equiv.
677	Garment	Miss.		10, 11, 15, 18 (Chief I.E.)	10.0–15.0			Exp. in Garment Ind.
678	Garment	Miss.		10, 11, 15, 18	5.0– 8.0			Exp. in Garment Ind. Des.
679	Education	Conn.		Asst./associate Professor				Doctor's Degree in I.E.
680	Pulp & Paper	Maine, Pa.		11, 31–37, 43, 49, 91	6.0–	Open		B.S.I.E.
681	Diversified Mfg.	Ill.	Ltd	10, 20, 91	7.5– 9.5	5–	30–50	I.E. Degree or Equiv.
682	Heavy Ind. Equip.	Wis.		10, 11, 13, 18, 21, 22, 90, 91	10.0–15.0	10–	35–	I.E. Degree
683	Plastics	Midwest		11, 19, 30–33, 35, 39, 40–44, 47, 48, 80	8.0–15.0	10+	30–45	I. E. Degree or Equiv.
684	Metal Fabrication	Mich.		36, 41, 53	10.0–15.0	4–	30–	I.E. Degree
685		Ga.	×	General (Exp. in Std. Cost)	6.6– 8.4	1–3		I.E. Degree

* The above 3 Pϕ have openings in New York City, Detroit, Mich., Syracuse, N. Y., Indianapolis, Ind., and Cleveland, Ohio

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Imp ovement
12	Suggestion Systems
13	Work Measurement and Perf. Stds.
14	Stop Watch Time Study
15	Std. Time Data Dev. & Applic.
16	Predeter. Elemental Time Stds.
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

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